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A QFD and ABC Based Capital Investment Evaluation Model for PCB Fabrication Industry

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Abstract:

The quality of decision-making in capital investing has a major impact on the future of companies in today's fiercely competitive business environment, especially for high-technology industries. Once a capital investment decision is made, the cost of related products in the future is partially determined.

This dissertation presents a new analytical model to help decision-makers to evaluate companies' capital projects, especially for highly automated industries like PCB fabrication. The proposed model uses customers' and experienced workers' voices in decision-making process. It ensures that the company's capital is spent on the right resources.

The proposed model incorporates Quality Function Deployment (QFD) and Activity-Based Costing (ABC) in the capital-investment decision-making process. It uses relationships between product quality and the related processes, which are identified with QFD, as a guideline to screen investment opportunities, then systematically realize the qualified opportunities, and use ABC to foresee the impact of qualified projects on product cost.

In this dissertation, three application indices are defined, using data in QFD, to aid decision-makers in making decisions in different types of capital projects. These three indices are: Superiority Index (SI), Confidence Index (CI), and Preferred Confidence Index (PCI).

Key words: Quality Function Deployment, QFD, Activity-Based Costing, ABC, capital investment, decision making, capital investment evaluation model, decision-making technique.

DEDICATION

To my parents,

Mr. Chin-Wan Chang and Mrs. Chin-Pin Chiu Chang

for their never ending love, encouragement, support, and prayers

Also,

To my lovely wife,

Tze-Mei Chen

To my parents in-law,

Mr. Ting-Huei Chen and Mrs. Mei-Yu Chiu

To my sister Mrs. Fang-Ling Chang, my brother in-law Dr. Alan Tsu-I Yaung, and my niece Stephanie Jin-Yu Yaung

To all of them I wish to express my heartfelt appreciation for their devotion and support.

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1. Introduction

1.1 Abstract

The quality of decision making in capital investing has a major impact on the future of companies in today's fiercely competitive business environment, especially for high-technology industries. Once a capital investment decision is made, the cost of related products in the future is partially determined.

This dissertation presents a new analytical model to help decision-makers to evaluate companies' capital projects, especially for highly automated industries like PCB fabrication. The proposed model uses customers' and experienced workers' voices in decision-making process. It ensures that the company's capital is spent on the right resources.

The proposed model incorporates Quality Function Deployment (QFD) and Activity Based Costing (ABC) in the capital-investment decision-making process. It uses relationships between product quality and the related processes, which are identified with QFD, as a guideline to screen investment opportunities, then systematically realize the qualified opportunities, and use ABC to foresee the impact of qualified projects on product cost.

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1.2 Overview

Decision-making is a critical process in human life. Humans have to make decisions on problems they face on the job or in everyday life. Problems have different characteristics. Decision making requires certain skills. The skills required in decision-making depend on the nature of the problem involved.

"Technical problems are neat and tidy when the answers can be computed with the traditional tools and equations of engineering science. But matters begin to get sticky when all unknowns can't be pinned down, or where several alternative actions appear to be equally desirable or undesirable. Then the all-important factor of human judgment comes into play. The key questions are how all of the important facts can be marshaled and how judgment can be brought to bear in the most rational and scientific way possible." "The scientific approach to decision making is often embodied in industrial engineering, and it is known by various names such as operation research, managerial economics, or management science. But perhaps the name quantitative analysis (not to be confused with the chemical variety) is the one gaining the most acceptance and is most descriptive in this broad field." "Despite the fact that the theory of quantitative analysis is still considered to be somewhat new, its foundations actually lie in a discipline known as **scientific management**[1], which was developed around the turn of the century." [Clayton Reeser, 1972; Ref. 1]

[1] Mr. Frederick Winslow Taylor, who graduated from Stevens Institute of Technology in 1883, is recognized as the father of scientific management.

The major body of quantitative analysis is rationality or certain assumptions. "The essence of quantitative analysis is rationality, or the assumption that the decision maker, armed with perfect information concerning the outcomes of various alternatives, will logically and without bias choose that one alternative that will maximize the use of his resources." [Clayton Reeser, 1972; Ref. 1]

Not until World War II did scientific management acquire the sophistication of advanced mathematical techniques for problem solving. After then, these mathematical developments, such as linear program and queuing theory, were followed by critical path scheduling (PERT) in the mid 1950s, and by the expansion of original notions of simulation. The practical applications of quantitative analysis were made possible by the development of the digital computer in the 1950s. Today, in management, we still face the same challenge: *how all the important factors can be brought into decision process and how to make decision scientifically.*

In past decades, the business environment had become more and more challenging. The time span between product generations is decreasing. What companies are facing is a multi-dimensional business. Companies compete with their rivals in added services, product cost and quality, etc. To handle the current fast changing business environment, many companies use capital investing as a strategic and tactical tool to gain market advantages. The competitive power of these companies in the future highly depends on how well they use their capital.

The quality of decision-making in capital investing has a major impact on the future of a company. Once a capital investment decision is made, the future cost of related products is partially determined. Thus, company's competition power in the future is partially determined. What is involved in capital investment decision-making is a broad field of knowledge, from market to manufacturing to customer service. To make a successful capital investment, a company has to make decisions based on its own strengths and weaknesses according to customers' perceptions. In other words, a company has to find out what its status is in the market: how do its products meet customers' expectation? And what is the status of its competitors? These kinds of information should be used as guidelines for the company's capital investment.

Capital projects with different focuses have been approached with different evaluation models. The purpose of evaluation is to foresee how an individual capital investment will impact a company and whether the valuable resources are used on right targets. In the past, many researchers and industry practitioners had approached the evaluation of a company's capital investment in many ways. Some of them were based on the capital budgeting method. They used conventional direct economic costs and benefits to evaluate an investment opportunity. These kinds of evaluation methods do not include the qualitative factors in the evaluation. These qualitative factors are very important in today's business environment. "Capital budgeting models are the most common models in the choice of technology in manufacturing" [R. Swindle, 1985; Ref. 2] [A. E. Diaz, 1986; Ref. 3].

The criticisms about these models are: 1) They are not able to deal with non-monetary factors in technological decision-making [V. Sundararajan and M. N. Sharif, 1983; Ref. 4] [H. Shaiken, 1985; Ref. 5]. 2) They are also not able to deal with environmental uncertainties and estimation inaccuracies [W. G. Sullivan, 1986; Ref. 6]. 3) They cannot manage multi-objective decisions [Paul R. Kleindorfer and Fariborz Y. Partovi , 1990; Ref. 7]. 4) Lastly, they disregard Strategy [Paul R. Kleindorfer and Fariborz Y. Partovi , 1990; Ref. 7].

To overcome these disadvantages of the conventional method, models that integrate business strategy and company's resources have been introduced. "These models could be grouped into: expert system models, linear programming-based models, multi-attribute utility models, and analytic hierarchy process (AHP) models" [Fariborz Y. Partovi, 1999; Ref. 8]. These models also have their advantages and disadvantages.

The purpose of this dissertation is to develop an evaluation model that could incorporate all the important items into the evaluation process. The proposed model combines the detailed manufacturing process break down and QFD and ABC tool to foresee how the decision could impact the cost of the product.

1.3 Research Questions

This research will focus on building an analytical evaluation model that could help decision-makers to focus on important criteria for capital projects and studying the impact of QFD and ABC on capital investment evaluations of the PCB fabrication industry. The ultimate goal of this research is to build a capital-investment evaluation model that will help decision-makers to evaluate capital investment alternatives based on priorities using QFD and ABC.

In today's business environment, customer requirements are the highest priority. A good capital investment evaluation model should, at least: 1. Provide a mechanism for decision-makers to incorporate the customers' requirements into decision-making process; 2. Provide a mechanism for assessing competitors' status; and 3. Provide insight into cost information on products.

In order to study the impact of QFD and ABC on capital investment evaluation, four models will be built: a general model, a QFD model, an ABC model, and an integrated model – model with QFD and ABC.

This research will start by answering the following question:

- ***What activities should be encompassed in a capital investment evaluation system for the PCB fabrication industry?***

After this question is answered, a general model of capital-investment evaluation system will be built, based on the answer. Then the QFD model, ABC model, and integrated model will be built to answer following questions:

- ***Will QFD improve the quality of the evaluation process and what are the impacts of QFD in the capital investment evaluation stage for the PCB fabrication industry?***
- ***Could ABC provide insight to cost information in the capital investment evaluation stage of the PCB fabrication industry?***
- ***Will there be a synergy effect if QFD and ABC are integrated into a capital-investment evaluation model?***

1.4 Research significance and contribution

In the past, most studies on capital investment evaluation focused on decision-making tools and processes. Focusing on the selection phase is somehow myopic. “The most significant deficiency of these studies is their limited focus on project evaluation and risk analysis tools rather than the entire investment decision-making process.” [Robert T. Kleiman, Edward J. Farragher, and Anandi P. Sahu, 1999; Ref. 9] “Focusing on the simple selection phase is myopic, and a more global approach is necessary to fully understand the capital budgeting process.” [G. Pinches, 1982; Ref. 10] A capital investment evaluation model that focuses on global approaches is needed.

This research makes the following contributions: 1. Building a systematic and structured model that focuses on global capital investment evaluation processes. 2. Integrating QFD into the model to allow decision makers inject the customer voices into the decision process. 3. Integrating ABC into the model to help decision-makers get more accurate cost information on products.

1.5 Validation of Research Hypothesis

Experts in making capital decision in the PCB industry were surveyed to determine the validity of the approach suggested. See section 5.2 for result.

2. Literature Review

2.1 Decision-Making Models

Over the last few decades, companies have tried different ways to improve their competitiveness in the market. Some industries, such as semiconductor manufacturing, are very capital-intensive. Capital investing becomes the most efficient way to gain competitiveness.

Some researchers try to approach it in other ways. "Researchers at Stanford University, in collaboration with other universities have built a large interdisciplinary research program which has the goal of replacing capital investment with technological innovation as the main diver of this industry" [Paul Losleben, 1990; Ref. 11]. "The strategy of this program is simple: utilize the dramatic improvements in cost/performance of computer technology to replace manufacturing methods which have been become prohibitively" [Paul Losleben, 1990; Ref. 11]. No matter which approach companies adopt, it always involves investment, either investing directly, in manufacturing equipment, or indirectly, in supporting facilities. Now, the questions become: How efficient will the capital investment be? How will an individual capital investment impact company's competition power? How does a company evaluate investment alternatives?

Each project has a different focus. Based on project focus, different evaluation models have been developed. As an example of these models "We introduce a dynamic programming method to determine the optimal design decision which minimizes the product cost under the strategic constrain given" [Chi J. Ho and Chan S. Park, 1993; Ref.

12]. Ho and Park developed a multistage integrated model that uses computer programs. They focused on product-design decisions in a concurrent engineering environment.

In the literature review of this research, the author groups these models into: expert system models, linear programming-based models, multi-attribute utility models, and analytic hierarchy process (AHP) models. Also included in the literature review are: Quality Function Deployment (QFD), Activity Based Costing (ABC), and PCB fabrication industry.

2.1.1 Decision-Making Models Overview

Decision-making is an important process of personal life. Which movies to watch? What DVD to rent? Even what restaurant to dine at? Compared to decision-making in personal life, decision-making in business is more complicated. Decision-making is the main part of business management. When a company gets a call from a customer, manager has to decide what the best way to satisfy customer is. The difference between decision-making in personal life and business is that only the decision maker evaluates most decisions made in his/her personal life, but other parties evaluate most decisions made in business.

Based on the nature of the problems, there are different ways to improve the quality and response time of decision-making. For problems that recur frequently, such as customers calling for technical support, the computer Expert System (ES) could help to locate the solution fast and reduce the service time. For problems like capital-investment evaluation, there are too many factors to be considered to make a good decision, the human involvement is higher than in other kinds of decision-making in business.

The following paragraph will review different types of modern decision-making or decision-support systems.

2.1.2 Expert System (ES) Models

Expert systems, by nature/cost effectiveness/service efficiency, are suitable for handling problems that occur frequently, especially for handling problems with pre-decided solutions. A fixed solution means that solutions to the problem are available and well studied. As long as the user could tell what problem is, the solution can be found. Conceptually, the major task of problem solving is matching the problem and its optimal solution(s).

2.1.2.1 Expert System Overview

Applications of artificial intelligence (AI) had been used in many fields to assist human in data collecting and interpretation. An expert system (ES) is one type of AI system. ES was developed in late 1960s. Not until the1980s, ES was widely adapted and made more economic. Researchers and practitioners started to implement ES in their fields and saw ES in their own views. "…. One type of system being developed is the expert system, which models in the computer the knowledge possessed and exercised by an expert in a narrow, confined discipline or pursuit. The expert system consists of a knowledge base and an inference procedure" [Edward K. Yasaki, 1980; Ref. 13]. "Expert systems are computers embodying rules and strategies of human experts: problem solvers, consultants, and professionals" [Robert Arnold Russel, 1982; Ref. 14]. ES applications in early 1980s were limited and focused on very specialized fields. In 1983, Steve Shirley published an article about how many, in which major fields, and how ES was implemented: "The expert computer emulates humans when it solves problem. It relies on past experience to solve problems. Knowledge to the computer is a set of rules that are used to select alternatives and draw conclusions." "Today, there are fewer than 50 high performance (ES) systems operating. They are used mainly in the fields of medicine, science, engineering, and defense" [Steve Shirley, 1983; Ref. 15].

2.1.2.2 Business Applications and Challenges of ES

The development of business applications of ES before early 1980s was slow. The reasons for the slow development of ES could be explained thus "(ES) Business systems were developed slowly because business applications involve more behavioral variables that can slow down acceptance of such systems". In this article, the author also points out the importance of ES applications to business, and in what type of business ES could be implemented: "Expert system for business are usually deductive; the basic function used by them is pattern matching. Among the business areas that could take advantage of expert systems are management consulting, financial decision, strategic planning, marketing, production, and personnel. A more immediate use of expert system is in education and training. Ignoring expert systems may put companies at a competitive disadvantage in next decade" [Robert Michaelsen and Donald Michie, 1983; Ref. 16]. In the 1980s, when industry practitioners tried to implement ES to solve problems, they faced other new problems. Some of these problems still exist today. Typical examples are "The problem is that most data processing managers have little experience in developing expert system," "the most likely candidate for an expert system application is a critical situation that may only occur infrequently but that requires the services of highly skilled expert," "once an application is selected, top managers must be convinced to spend $1 million to $3 million on a prototype," and "Designing the system is the next major problem, as the design process is an inexact technology that often results in inexact programs" [Jan Johnson, 1984; Ref. 17]. Other author also pointed out other problems. "In fact, most expert systems have no more intelligence than conventional programs. They can recognize patterns of symbols, but they cannot deal in mental images, analogies, and other ambiguous elements of human thought. In addition, much human knowledge is intuitive and difficult to put into concrete rules in a computer" [Tom Alexander, 1984; Ref. 18]. "Expert system programs are applicable in specialized problem domains requiring specialized knowledge and skill" [F. Nelson Ford, 1985; Ref. 19]. Some examples are " ES might be useful in the areas of 1. accounting standards, 2. auditing, 3. taxation, 4. management and control. The use of ES and ' intelligent knowledge based systems' will have a great effect on the work and careers of accountants, and the profession has to formulate policy in this area" [Greg Stoner, 1985; Ref. 20]. "ES are also beginning to be used in industrial applications. Types of ES include: 1. predictive, 2. planning, 3. instructional, 4. design, and 5. monitoring" [Richard Vedder and Chadwick H Nestman , 1985; Ref. 21] . Today, ES is seen in action in: 1. Computerized Customer

Service 2. Automatic Directory Service 3. Car Diagnostic Systems 4. Banking Systems 5. Tax Filing Systems.

2.1.2.3 Summary of ES

Compared to humans, ES can achieve high levels of performance. "The knowledge-based expert system is a promising technology for solving decision-making problems. Such a system can achieve high levels of performance on problems that normally take years of special education and training for human to solve the private knowledge of a human expert is turned into a 'knowledge base' for the particular area in which the human is considered expert." [Edward L. Fisher, 1985; Ref. 22].

The advantages of ES can be best described as "An ES replaces human intelligence with machine intelligence for various tasks. Advantage include: 1. saving money over human expertise, 2. better quality, 3. ability to handle complexities, and 4. compatibility with managers' decision style." [Efraim Turban and Teodore J. Mock , 1985; Ref. 23]. ES has its limitations in implementation: "Limitation are 1. expertise is hard to extract from humans, 2. ES decisions are not creative, and 3. the knowledge acquisition usually requires a knowledge engineer." [Efraim Turban and Teodore J. Mock, 1985; Ref. 23]

As mentioned above, ES uses human expertise as models for making decisions. These decision-making models can be tailored to match managers' decision-making styles. ES is excellent for applications requiring repeating same decision-making process on a well-learned problem. The major challenge is that ES is not creative. With subjects that have never been studied, ES cannot help.

2.1.3 Linear Programming-Based Models (LPBM)

Unlike ES systems, LPBM deals with certain levels of uncertainties. In ES applications, the solutions related to problems are known and have been well studied. Once a problem is identified, the right solution can be located. In LPBM, the major application is to find an optimal solution under constrains. In other words, the solution is to be generated, which is different from ES.

LPBM is mostly used in finding an optimal solution under constrains. Each LPBM is developed to deal with a specific problem. Developers have to find mathematical equations that represent the nature of constrains and objective functions that represent the objective of interest - then with intensive calculations find the optimized solution for the problem. Before the computer era, LPBMs that dealt with multi-constrains were rarely put into business practice because of huge amount of calculation.

With the aid of a computer's computation power, researchers can now find the optimum solution for the problem they are dealing with in a more precise and timely manner.

2.1.3.1 Linear Programming Based Models Overview

LPBMs heavily depend on computers. The creation of a linear programming model starts with developing a mathematical model. The mathematical model describes the characteristics of a problem to be analyzed. "The initial model may very well be a collection of intelligible and hopefully logical statements" [W. F. Porter, 1970; Ref. 24].

Developing a mathematical model requires certain amount of technical skill. To validate a mathematical model, it is necessary to test and demonstrate various decisions. The purpose of a computerized linear programming model is to verify the created models without major capital investment or interrupting the production, and in a time-efficient way.

To put LPBMs into business practice, especially as tools to help managers to make decisions, researchers had developed special programming classes to solve certain business problems. Minimax (Maximin) programming is one of the examples. Minimax programming is used to solve decision-making problems under uncertainties. [T. Kawaguchi and Y. Maruyama, 1976; Ref. 25] This class of application is from "Constrained games" in which the strategies of a rectangular game are subject to further linear inequalities. Typical applications of this class could be found in many planning problems, like farming planning problems and production-planning problems in a steel plant. [A. Charnes, 1953; Ref. 26] [J. C. C. Mckinsey, 1952; Ref. 27] [P. B. R. Hazell, 1970; Ref. 28]

To create a business application in LPBM, it is important to establish equivalence between the constrained business environment and the linear programming problem. The knowledge of how to establish this equivalence is one of the key factors for successful business applications in LPBM.

2.1.3.2 Business Applications and Challenges of LPBM

In addition to farm planning in agriculture and production planning in steel plants, LPBM applications can be found in projects such as journal selection for a library under cost constraints [D. H. Kraft and T. W. Hill Jr., 1973; Ref. 29], decision tools for dairy manure handling systems selection [D. A. Haith, L. M. Safley Jr., and D. R. Price, 1977; Ref. 30], and planning in R & D [A. E. Gear, 1974; Ref. 31] [Bernard W. Iii Taylor, Laurence J. Moore, and Edward Clayton, 1982; Ref. 32]. In some applications, developers combined LPBM with other managerial functions to solve problems like shop-floor scheduling [R. De Malherbe C. Boer, L. Lees, and M. C. De Malherbe, 1978; Ref. 33].

For applications that deal with multiple-criteria decision-making, the LPBM is embedded in the overall decision procedure. Managers with different decision-making styles will utilize different approaches to problem solving. [M. De Waele, 1978; Ref. 34] Researchers developed an interactive procedure to allow decision-makers to make decisions in their own styles and settings [Gary R. Reeves and Loi S. Franz, 1985; Ref. 35]. For problems like the fixed cost of an activity depends upon other activities that are also being undertaking, researchers had developed model called interactive fixed charge linear programming problem (IFCLP) to solve these problems [S. Selcuk Erenguc and Harold P. Benson, 1986; Ref. 36].

A plant that deals with multiple parts or product scheduling faces so-called multiple-objective linear programming for multiple-criteria decision-making problems. In today's business environment, managers face this kind of problem frequently. In this kind of problem, there is a preferred decision, not an optimal one [Peter G. W. Keen, 1979; Ref. 37]. The key to solving this kind of problem is creating a mathematical model that can identify the preferred decision. Because of the complexity of this kind of problem, the focus of problem solving has been switched to algorithms of complexity handling. Gordon M. Clark has demonstrated the algorithm in his research [Gordon M. Clark, 1986; Ref. 38].

As mentioned above, managers with different decision-making styles will use different approaches to problem solving. To make LPBM applications more decision-maker satisfaction oriented, researchers approached it by introducing “fuzzy parameters” in their models. This kind of LPBM application will result in a solution that makes decision-makers more satisfied [R. E. Bellman and L. A. Zadeh, 1970; Ref. 39] [H. Tanaka and K. A. Asai, 1981; Ref. 40] [H. Tanaka and K. A. Asai, 1984; Ref. 41] [S. A. Orlovski, 1984; Ref. 42] [Masatoshi Sakawa and Hitoshi Yano, 1985; Ref. 43].

Other LPBM applications could be found in: oil refineries; utility planning; computer optimization tool; simulations; and financial advising systems.

Managers make decisions based on objectives that they think will impact the final result. In today’s fast-changing business environment, these objectives become more dynamic. Some of these objectives relate to the personal judgment of the decision-maker. How to present this kind of human judgments in mathematical constraints or objective functions in LPBM applications is a challenge to LPBM researchers and industry practitioners.

Should applications turn human judgment into constraint equations or objective equations in LPBM? Or use LPBM to generate supporting data for related attributes in decision-making models that have independent attributes using humans as judgement-mechanism? This is a challenge for researchers and industry practitioners too.

2.1.3.3 Summary of LPBM

LPBM is used to find an optimal solution under constrains. In business applications, LPBM is used to find a preferred solution under constrains. When all defined constrains or objectives can be presented as constrain equations or objective functions in an LPBM, LPBM can be used as a major solution-finding tool. LPBM also could be used as a tool to create information to support decision–making. Most likely, this is a multi-objectives case.

When the inputs and constrains of problem that is being studied become fixed-pattern or even fixed-number, then the LPBM used for solving the problem could be turned into an ES. In an application view, LPBM could also be a supporting module in an ES if the constrains are well studied and controlled.

2.1.4 Multi-Attribute Utility Models (MAUM)

For frequently recurring problems with available well-studied solutions, most companies implement ES to help users to locate the right solution. For problems with certain constrains, companies could use LPBM to find the preferred solution if all independent constrains were represented as mathematical equations. When not all independent constrains can be presented in mathematical equations, the decision-makers' subjective judgment becomes one of key factors that impact the final decision.

When decision-making involves attributes that are defined in different domains, ES and LPBM are hardly the obvious solutions. A Multi-attributes utility model (MAUM) could be used to solve this kind of problem.

2.1.4.1 Multi-Attribute Utility Models Overview

Management science and decision science have grown exponentially since the mid-20th century. Two closely-related fields central to this growth are Multiple Criteria Decision Making (MCDM) and Multi-Attribute Utility Theory (MAUT) [Peter C. Fishburn, James S. Dyer, Ralph E. Steuer, Jyrki Wallenius, and Stanley Zionts, 1992; Ref. 44]. In operations research, Multiple Criteria Decision Making (MCDM) is one of the major research sub-fields. A general definition of MCDM is the solving of decision problems that involve multiple, and generally conflicting objectives [Stanley Zionts, 1992; Ref. 45]. And Multi-attribute Utility Model (MAUM) is based on MAUT.

Today, decision-making in business is no longer a one-dimension, or one-attribute, problem. Most decision-making problems are multi-attribute cases. The final decision depends on multiple attributes. Decision makers have to make final decisions based on the trade-off between objectives that depend on defined attributes. The trade-off is subjective. To avoid becoming too subjective, MAUM uses utility functions or curves for assigning values to relative attributes. Then, based on these attributes' utility values, decision makers make their decisions.

The following are procedures in MAUM: 1. Specifying the value attributes of interest; 2. Evaluating each outcome with respect to each attribute; and 3. Specifying a composition rule and scaling factor so that utility may be arithmetically aggregated across attributes[Gregory W. Fischer, 1977; Ref. 46]. Procedure 1 has a certain level of subjectivity. The attributes come from the group consensus of decision makers involved. Procedure 2 is objective if decision-makers use available utility functions, which are created based on historical data, to generate outcomes. With utility functions, each alternative's attributes will be evaluated based on its value and then given a utility value accordingly. For some attributes, there are no available utility functions. In these cases, the outcome will be determined subjectively. Procedure 3 is to weigh the attributes, calculate the relative weights of attributes, then multiply attributes' relative weights by their utility values accordingly as weighted utility values, and sum up the weighted utility values for each alternative solution. The final decision will be made based on each alternative solution's total weighted utility value.

Group decision-making is the nature of MAUM and involves human factors in its process. In MAUM applications, utility functions are key factors that impact the quality of the final decision, and most effort is spent on obtaining utility functions for individual attributes. The utility functions obtained encode decision-makers' behavior with respect to risk [G. Anandalingam and C. E. Olsson, 1989; Ref. 47]. As a result, the final decision is more subjective than solution generated by ES or LPBM.

When incorporated with other techniques like simulation, MAUM could be used as a tool for strategic decision. To make a successful application model for strategic decisions, the following are necessary: 1. an understanding of the various modeling techniques; 2. the ability to diagnose a real problem and select appropriate techniques; 3. the willingness to rethink the problem in terms of the modeling techniques; and 4. the construction of models with the full participation of the decision-makers [Sandor Schuman Patricia Reagan-Cirincion, George P. Richardson, and Stanley A. Dorf, 1991; Ref. 48].

Most decision-making problems managers face today involve strategic rationalization. MAUM is incorporated with other techniques to provide a good tool for this kind of decision-making in today's business. How to incorporate different techniques with MAUM to help decision makers make high-quality decisions is a good research topic.

2.1.4.2 Business Applications and Challenges of MAUM

MAUM applications can be used in many fields:

- Project selection. One example is the crisis in fresh water supply in Newport News area of Virginia (USA) [G. Anandalingam and C. E. Olsson, 1989; Ref. 47]. Another example could be found in construction project selection, where author incorporates fuzzy stochastic technique with MAUM [George Norman, Eric T. T. Wong, and Roger Planagan, 2000; Ref. 49].

- Environmental Planning. One example is the electric utility in Korea [Seung-Jun Kwak, Tai-Yoo Kim, and Seung-Hoon Yoo, 1998; Ref. 50].
- Model selection. One example is the brand-choice model selection in marketing [Nikolaos F. Matsatsinis and Andreas P. Samaras, 2000; Ref. 51]
- Resource allocation. One example is sales-territory assignment and resource allocation, where the author incorporates integer-goal-programming with MAUM [Richard H. Mcclure and Charles E. Wells, 1987; Ref. 52].

Above are some of typical examples of MAUM business applications. Many other MAUM applications could be found in the operation research field.

Like ES and LPBM, MAUM also faces challenges. MUAM depends heavily on decision-makers. First, in attribute selection, different groups of decision makers could result in different sets of attributes, which means that the result could be subjective. Second, in utility-function selection and utility-value assignment, different groups of decision makers could select different utility functions and assign different utility values to each attribute. This means that the result is subjective. Since the obtained utility functions encode the decision makers' behavior toward risk, this means that the result could vary from time to time. How to avoid subjectivity and being inconsistent with time is the most challenging topic in MAUM.

2.1.4.3 Summary of Multi-attribute Utility Models

Measures of criteria in multi-attribute decision-making could be classified into two categories, quantitative and qualitative. In MAUM, decision makers have to express the qualitative measures of attribute value and the importance of the attribute into quantitative ones. MAUT provides a mechanism for converting expressions, or verbal value, of criterion importance, into quantitative form. And utility functions or graphs provide mechanisms to convert attribute values that are in verbal form into quantitative form. Many researchers have compared different methods and systems for multi-criteria and multi-constrains decision-making [D. Timmermans, 1991; Ref. 53] [D. M. Buede and R. W. Choisser , 1992; Ref. 54] [H. M. Moshkovich, O. I. Larichev, A. I. Mechitov, and D. L. Olson, 1993; Ref. 55] [D. Olson, 1992; Ref. 56]. From these studies, there is a consensus that one of the most important criteria for the evaluation of a decision method is obtaining the "right" decision. Olson concludes that more attention should be given to the means of testing judgment consistency, and that, in some cases, attempts to solve decision tasks through more "exact" judgments of value-function parameters may lead to erroneous results [D. L. Olson, O. I. Larichev, H. M. Moshkovich, and A. I. Mechitov, 1995; Ref. 57].

In decision-making, decision makers may have question about "How exact is enough?" for the data that their decisions are based on. Truly, how exact should the data be to help decision makers make "right" judgment? Many researchers and industry practitioners have been working on Decision Support Systems (DSS) to supply more “exact” data for decision makers to make the “right” judgment. This is a promising development, and many MAUM researchers’ focus has switched to this field.

2.1.5 Analytic Hierarchy Process (AHP) Models

In today's fast-changing business environment, not all the related historical data used in the models described in above are readily available for decision makers, who have to make decisions based on what ever data they have. AHP is one of the most popular and widely used decision-making tools in this kind of problem.

2.1.5.1 Analytic Hierarchy Process overview

"The Analytic Hierarchy Process (AHP) is a multiple objective decision making tool that consolidate information about tangible and intangible criteria and alternatives in the decision making process." [Kai H. Lim and Scott R. Swenseth, 1993; Ref. 58]. It provides ration-scale measurements of priorities of elements in various levels of a hierarchy. It utilizes the concept of pair-wise comparisons to arrive at a scoring and rank ordering of alternatives under consideration. "These priorities are obtained through pair-wise comparisons of elements in one level with reference to each element in the immediate higher level."[N. Vinod Kumar, and L.S. Ganesh, 1996; Ref. 59]. "The decision makers provides a subjective cardinal judgment about intensity of his preference for each alternative over each other alternative under each of a number of criteria or properties." [R.C. Van Den Honert, 1998; Ref. 60]. The essential steps of AHP could be best conceptually illustrated by "assum(ing) that this has been done for a three-level hierarchy (no sub-factors) and such a hierarchy has been constructed. From that point on, we proceed as follows:

Step 1 Weight the factors (attributes).

Step 2 Weight the alternatives with respect to each factor.

Step 3 Weight the alternatives.

The three steps may seem confusing, but each proceeds logically from first to the next." [Hans J. Lang and Donald N. Merino, 1993; Ref. 61]. If more levels of hierarchy are needed, step 2 needs to be repeated, and "weight sub-factors in each factor against each factor" need to be used instead of "weight the alternatives with respect to each factor." And the last second step is to "weight(ing) the alternatives with respect to each sub-factor." For overall problem solving using AHP, "AHP is a process for solving decision problems using the following five steps.

Step 1 Create a decision hierarchy by breaking down the problem into a hierarchy of decision elements.

Step 2 Collect input by a pair-wise comparison of decision elements.

Step 3 Determine whether the input data satisfies a "Consistency Test". If it does not, go back to Step 2 and redo the pair-wise comparisons.

Step 4 Calculate the relative weights of the decision elements.

Step 5 Aggregate the relative weight to obtain scores and hence ranking for the decision alternatives."

[Stanislav Karapetrovic and E.S. Rosenbloom, 1999; Ref. 62]

The major advantage of AHP is that it does not require advanced knowledge of mathematics, special skills in computer programming, or historical data like those used in Multi-Attribute Utility Model. Decision-makers can weight the decision elements based on their experience, although the result may be somehow subjective.

2.1.5.2 Business Applications and Challenges of AHP

Unlike other decision-making models, AHP does not require special resources to process data. It could be used in anything from personal to business decision-making. The following are some examples:

- Personal property-purchase selection. One example is car selection [Dae-Ho Byun, 2001; Ref. 63].
- Vendor selection. One example is vendor selection of a communication system [Maggie C.Y. Tam and V.M. Tummala Tao, 2001; Ref. 64].
- Strategic planning in manufacturing systems. One example is a equipment replacement decision [William J. Kolarik, Henning Oeltjenbruns, and Ralf Schnadt-Kirschner, 1995; Ref. 65].
- New equipment purchase. One example is comparing two machines for improving capacity, quality, and productivity [D.I. Angelis and C.Y. Lee, 1996; Ref. 66].
- Product screening. One example is new product screening [Anthony Di Benedetto, Roger J. Calantone, and Jefferey B Schmidt, 1999; Ref. 67].
- Capital investment. One example is a decision about new ventures [Barin N. Nag and Bharat A. Jain, 1996; Ref. 68].

Although AHP is a convenient and powerful tool for decision-making, it faces few challenges. One of the major challenges AHP faces is that the result is subjective. Researchers had proposed models to enforce AHP, likes multiplicative AHP, “since it (AHP) is essentially based on ratio information, (it) can be converted to a variant with multiplicative structure. This form of AHP is commonly referred to as the multiplicative AHP" [R.C. Van Den Honert, 1998; Ref. 60]. Other researchers incorporate other techniques into AHP to avoid subjectivity, models like Fuzzy AHP [S.C. Chi, R.J. Kuo, and S.S. Kao, 1999; Ref. 69].

The other challenge AHP faces is that the traditional approach is based on certain (deterministic) pair-wise preference judgments of AHP. If the preference statements are presented by judgment intervals, the result of traditional from a traditional AHP analysis based on single judgment values may be reversed and, therefore, incorrect. To solve this problem, researchers have developed multivariate statistical techniques to obtain both point estimates and confidence intervals of rank reversal probabilities [L. G. Vargas, 1982; Ref. 70] [T. L. Saaty and L. G. Vargas, 1987; Ref. 71] [A. Arbel, 1989; Ref. 72] [A. Arbel and L. G. Vargas, 1993; Ref. 73] [C. G. E. Boender, J. G. De Graan, and F. A. Lootsma, 1989; Ref. 74] [A. A. Salo, 1993; Ref. 75] [Antonie Stam and A. Pedro Duarte Silva, 1997; Ref. 76] .

Academic researchers and industrial practitioners have been implementing AHP in more applications in recent years. How to avoid the two challenges mentioned in each application will be a challenge for researchers.

2.1.5.3 Summary of Analytic Hierarchy Process

The advantages of AHP include: structured approach; combining customer wants and internal objectives of company to evaluate alternative projects; flexibility in criteria selecting; and that no massive accounting and measurement system are required. The disadvantages of AHP include ignoring the direct assessment of the competitor's status and its importance in selecting capital projects [Fariborz Y. Partovi, 1999; Ref. 8].

In decision-making, decision makers use tools/decision models to help them make "right" decisions. These tools or models help decision makers map their personal judgments onto the final decision or to generate objective decision-support data. Some of the models, such as expert system, require experience in similar cases to build. Some of the models, such as linear programming based model, require special knowledge of mathematics to build. Models like Multi-Attribute Utility require accumulated historical data. In problems like new ventures, decision-makers could face two challenges: 1. No experience in similar cases. 2. No historical data, like those used in multi-attributes utility model, on hand. In such a case, decision makers have to make a decision based on their personal preference. AHP could help decision makers to make decisions even where there is no relevant historical data or experience in similar cases. It utilizes the pair-wise comparisons between alternatives to reach decisions. This is the advantage of AHP. As mentioned in the previous section, the results of AHP could be subjective if no other tools were incorporated in the process.

The result of AHP is highly related to the personal preference of the decision makers. To avoid subjectivity, decision-makers can adapt the models mentioned in section 2.1.4.2. The trade-off is that, the more tools are incorporated into AHP, the more complicated it becomes. The simplicity of AHP process is sacrificed. How to make the trade-off is up to the decision makers.

2.2 Quality Function Deployment (QFD)

QFD was first introduced in Japan by Dr. Yoji Akao in 1966. In 1972, Mitsubishi Heavy Industry put it in practice at Kobe Shipyards.

Translating customers' requirements into product design requirements and relative production requirements is the most popular application of QFD. The house of quality is the focus of QFD. The customers' requirements are sometimes called customers' voice. The main idea is: quality of a product is defined by customers, not engineers. This kind of concept is mainstream of today's business practice. A frequent heard term is "injecting customers' voice into the product design". –Customer requirements are often stated in non-technical or non-measurable terms. With QFD, these non-technical terms could be analyzed and converted into technical specifications. The structure of QFD is simple. The process of data analysis and converting is a complex and time-consuming one. This is often owing to the subjective nature of data itself and the potential complexities of the QFD charts.

2.2.1 Advantages of QFD

In the traditional approach, sequential product design approach, some design defects will not be found until the final stages. To correct this kind of design defect, the design process has to start over from the early design stage. In QFD, the process requires a multi-disciplinary team. With a multi-disciplinary team, design defects that will result in costly prototyping and time consuming re-design can be found and solved in the early stages of design.

QFD is not only a map for product design. It is also a map for quality improvement for current products. With the House of Quality, a design team could see how a company's product met customer requirements and what the market position of company's product regarding to "qualities" was. This will provide directions for market and quality improvement.

Currently, data mining is a hot issue. In today's computer era, every one is flooded by information. There is a great deal of information involved in designing a product, . How to present correct information in the correct format becomes one of the key issues in product design. If information is presented in the wrong format, this could result in longer design time or even faulty design. QFD provides a good data-presenting format for product design. QFD is also a good format of data presentation for supporting other kinds of decision-making.

2.2.2 Applications of QFD

- Tool for product development

Being able to translate customer requirements into design specifications, QFD is mostly used as a product development tool. With QFD, the product-design team can not only inject quality into product design but also reduce the time-t-market for new products: "The matrix approach (QFD) also can be used to analyze critical processes to determine critical process parameters. This information, when couple with designed experiments and Statistical Process Control (SPC), can assist in improving the final product delivered to the customer" [Kevin C. O'brien, 1992; Ref. 77].

- Tool for performance measurement

The principle of mapping customer requirements onto engineering characteristics in QFD may also be applied to mapping the customer requirements onto performance measures: "This QFD based tool can be used to identify the performance measures that closely reflect the concerns of the customer and to ensure that these performance measures are used (and measured) in the re-engineering business process" [H. Jagdev, P. Bradley, and O. Molloy, 1997; Ref. 78].

- Tool for concept selection

QFD also could be used to select concepts. "The way we chose to rapidly and accurately identify the high payoff concepts was the use of Quality Function Deployment (QFD) as a formal systems engineering tool in an Integrated Product Team Environment" [Matt Vance and Don Hess, 1998; Ref. 79].

2.2.3 Advanced Applications of QFD

- Tool for improving the quality of technical planning

When incorporated with S-curve analysis, QFD can be used as a forecasting methodology to improve corporate technical planning. "This methodology should provide R&D managers with powerful tool for selecting an optimal portfolio of research projects, including process research, which reflect the strategic needs of the company" [P. Mclaughlin and Jeffrey K. Stratman, 1997; Ref. 80].

- Tool for determining the product's market price

In a market where the quality difference between all competing products is not noticeable, the price of the product becomes the focus of quality: "QDM means Quality Deployment for Marketing Pricing. ….. propose a theory and method of determining product quality and targeting selling price. The quality deployment of QFD shall be applied in this method" [Toshiyuki Mochimoto, 1997; Ref. 81].

- Tool for strategic capital budgeting

When incorporated with AHP, QFD could be used as tool for strategic capital budgeting: "This model which is based loosely on quality function deployment (QFD), includes integer programming to determine the allocation of funds to various technological projects. The method combines the information related to the market position and the voice of the customer to determine in which technologies limited resources of the organization are best invested" [Fariborz Y. Partovi, 1999; Ref. 8].

2.2.4 Summary of QFD

- QFD is an excellent data presentation format for analysis task.

QFD reveals the structured relationship between requirements and expected results. To make a good decision effectively and efficiently, it is necessary to collect correct data and present it in a suitable format. As a well-accepted concept, “garbage in garbage out “, it is of no question that the correctness of the data has a major impact on decision quality. How about the data presentation format? The presentation format of data will impact the efficiency and effectiveness of data usage. A good data-presenting format not only presents all necessary data at the same time, but it also shows the relationship between data. QFD provides both. Thanks to its matrix format, QFD also provides tractability between data

- QFD provides an systematic way to analyze relationships between requirements or between expected results.

QFD not only allows the user to analyze the relationships between requirements and expected results, it also allows users to analyze the relationships between requirements or expected results. This provides a user with a tool to eliminate unnecessary requirements.

- QFD promotes the concurrent working environment for the decision-making process.

QFD is a well-known and proven tool for facilitating product design by requiring a cross functions team. This kind of cross-function working style is called concurrent engineering. Compared with traditional sequential design processes, concurrent engineering has a shorter design cycle time. In addition to the cycle time, the data format embedded in the QFD process also help the decision maker to make a better decision by showing a clear relationship between requirements and actions. The same benefit could be applied to capital investment decision-making process.

In practice, QFD could be a communication format for users and a place for personnel from different departments to exchange or consolidate expertise.

2.3 Activity-Based Costing (ABC)

2.3.1 ABC Overview

"The goal of ABC is *not* to allocate common costs to products. The goal is to measure and then price out all the resources used for activities that support the production and delivery of products and services to customers." "Activity-based costing (ABC) was developed to provide more accurate ways of assigning the cost of indirect and support resources to activities, business processes, products, services, and customers. ABC systems recognize that many organizational resources are required not only for physical production of units of product but to provide a broad array of support activities that enable a variety of products and services to be produced for a diverse of customers" [Robert S. Kaplan and Anthony A. Atkinson, 1998; Ref. 82].

"The basic concept behind product costing in ABC system is that the cost of a product equals the cost of raw materials plus sum of the cost of all activities required to produce the product. The ABC system recognizes that while some of the overhead resources increase in proportion to the volume of products produced, the rest of the overhead resources are not" [N. S. Ong and Len Yeo Lim, 1993; Ref. 83].

2.3.2 Advantages of ABC

- Reflects a cause-to-effect relationship between the service department and production department

Without a cause-and-effect relationship, the costs of many service departments cannot be assigned to production departments. In both traditional costing systems and an

ABC system, direct costs are assigned to products in the same way. Indirect costs, such as service department expenses including purchasing, product design, and scheduling are assigned to product in different ways. “ABC system provides a mechanism for establishing causal relationships between expenses that must be treated as common or joint in traditional cost systems” [Robert S. Kaplan and Anthony A. Atkinson, 1998; Ref. 82]. In an ABC system, the designer links resource expenses to activities performed.

- Does not need extensive time-and-motion studies to link resource spending to activities performed

“The goal (of ABC) is to be approximately right, rather than precisely wrong, as are virtually all traditional product costing systems.” “Many traditional cost systems calculate product costs out to six significant digits ($5.71462 per unit), but, because of arbitrary allocation procedures, the first digit is usually wrong” [Robert S. Kaplan and Anthony A. Atkinson, 1998; Ref. 82]. ABC data that links resource expenses to activities performed are usually obtained from surveys or interviews. In the surveys or interviews, individuals are asked to estimate the percentage of time, not how much time, they spent on any activity on the activity list for their jobs.

- The cost of product-sustaining and customer-sustaining activities is easily traced to the individual products.

Traditional systems cannot trace product-sustaining and customer-sustaining resources to individual products and customers. In ABC, the cost of product-sustaining and customer-sustaining activities is easily traced to the individual products and services for whom the activities are performed, but the quantity of resources used is independent of the production and sales volumes for the product and customers.

The ABC system uses activity-cost drivers as linkages between activities and cost objects. An activity-cost driver is a quantitative measure of the output of an activity. In addition to traditional unit-level cost drivers, such as labor and machine hours, ABC systems require the use of activity-cost drivers that can trace batch, product-sustaining, and customer-sustaining activity costs to products and customers.

2.3.3 Comparison of Conventional Costing Systems and ABC Systems

The major difference between conventional costing systems and the ABC system is the supporting cost assignment. The conventional costing system uses an overhead allocation approach to assign supporting costs to products. There will not be cost distortion if a company has only a single product. When the production is used for a mix of products, the cost distortion becomes a serious problem. The ABC system can solve this problem by assigning supporting costs to products based on how much supporting resources each product consumes. The cost information is more accurate. For a highly automated industry, such as PCB fabrication industry, supporting cost has major impact on the cost difference of products between companies. The ABC system is superior to conventional costing system.

2.3.4 Advanced ABC – Feature Costing, a Better Approach

There are reasons why ABC is still not a primary cost accounting system. In 1998, Balachanran & Thondavai indicated in their article, "What's going wrong with activity-based costing": "there are nine pitfalls to avoid to implement ABC system: 1. Failing to perform adequate litmus tests to determine whether ABC is right for you. 2. Failing to understand the strategic nature of the business. 3. Failing to obtain top management commitment and sustained support. 4. Failing to clearly define scope, goals, and objectives. 5. Failing to train the team member. 6. Relying on complex software and external consultants. 7. Failing to empower team members. 8. Focusing on changing culture versus changing behavior. 9. Focusing on short-term breakthroughs versus long-term continuous improvements" [Bala V. Balachandran and Nandu N. Thondavadi, 1998; Ref. 84].

In 1999, Brimson & Antos indicated their article, "Feature Costing: Next Step in ABC Evolution": "The ABC paradox is that the more detailed an ABC system becomes the more useful it becomes to operational people yet the harder the system becomes, to maintain." "Activity-based costing (ABC) has transformed the way executives would like to manage product cost, but in its current form it will never become the primary cost-account system in most company. ABC systems are very complex and accounting data is not collected in a manner that is consistent with maintaining activity information. These difficulties have given rise to the ABC paradox." "The natural consequence is to reduce the number of activities. The system becomes labeled an accounting system an is not actively used by operational people, because it is less relevant to their needs" [John Antos and James Brimson , 1999; Ref. 85].

Brimson and Antos proposed an alternative approach to ABC: Feature Costing. "Feature costing is far superior to both conventional overhead allocation and the two-stage cost-driver approach that is prevalent in ABC. The reason for this superiority is that feature costing is built on process-management model. Process management develops an understanding of the process and the factors that cause the process to vary. The appeal of feature-costing approach is that it reduces the complexity of computing a product's cost while facilitating a more detailed activity analysis." "A final advantage of feature costing is that it relates a product to the factors that cause process-cost variation. This facilitates a better understanding of how to improve process and lower product costs. Feature costing enables a large number of products to be costed with much less work than ABC (two-stage approach)" [John Antos and James Brimson , 1999; Ref. 85]. The reason for using the feature cost approach is that common word regarding to a product is "feature". Feature is the most commonly used word for communicating across departments. Consumers also use features to profile a product. A future study of the feature costing approach is very promising.

2.3.5 Road Map for Building ABC Systems

a. Identify activities that are performed by the support department.

To identify the activities being performed, a survey or interview with the process owner is conducted. The purpose of a survey or interview is to generate a list of activities. Activities performed could be classified into three categories: unit-level activities, batch-level activities, and product-sustaining activities. Unit-level activities are those performed for every unit of product or service produced. Batch-level activities are independent of the number of units, such as machine set-up, material purchase, and order processing. Product-sustaining activities are performed to enable product production, such as product design, technical support, and market research and support.

b. Trace resource expenses of support resources to activities

The purpose of tracing resource expenses of support expenses to activities is to work out the activity cost drivers. Process owners write down how much time they spend on performing each individual activity. For a resource like space, what percentage of capacity is committed to each individual product is estimated. The activity cost driver is equal to the total resource cost and is divided by the total working hours and then multiplied by the percentage of resource usage.

c. Trace activity costs to product

Activity-cost drivers are used as linkages between activities and products to assign activity costs to products. In this way, costs like batch, customer sustaining, and product sustaining, could be assigned more accurately to individual products.

Steps b & c are named as ABC two stages cost-driver approach.

2.3.6 Summary of ABC

- ABC is superior to conventional costing systems in providing more accurate cost data

Most high-technology industries are highly automated. The conventional costing systems use an overhead approach to assign product-sustaining and customer-sustaining costs to products. If the company has only a single product, the cost distortion is not serious. If the company has a mix of products, the cost distortion becomes a serious problem. Traditional costing systems do not attempt to identify, accumulate, or report costs by activities performed, like ABC systems do. So, ABC systems could help managers to allocate these product-supporting costs to products more correctly.

- The ABC system can turn many indirect costs into direct costs.

One of the most important differences between traditional and activity-based costing systems is the extent of allocation [Gary L. Sundem, Charles T. Horngren, and William O. Stratton, 2002; Ref. 86]. Traditional costing systems allocate only production costs to products. ABC systems allocate the cost beyond production to overall value chain functions, processes such as marketing and customer service, etc.

- ABC systems provide stronger relationships between activities.

Based on the relationship between identified activities and resources, managers could trace indirect costs to cost objectives. Managers would have greater confidence in the accuracy of cost information.

- ABC systems are more complex and costly than traditional costing systems.

The ABC system classifies more costs as direct costs than do traditional costing systems. The more cost classification there is, the more complex the system will be, and the more the system construction cost will be. Although the cost becomes an issue, more and more industries are adopting ABC systems.

2.4 Capital Investment Evaluation Models

2.4.1 Overview

Should capital investment be a tactical or a strategic move? It is well accepted that decisions made within an organization could be categorized as tactical and strategic. “those that are well structured, routine, and which require few resources (tactical); those that are ill structured, unique, and which require substantial resources (strategic)” [Theresa J. B. Kline, 1994; Ref. 87].

Tactical decision-making has been systematically studied for more than 40 years [J. R. Busemeyer, M. K. Stevenson, and J. C. Naylor, 1990; Ref. 88]. In 1954, Edwards described the characteristics of such decisions as those with no risk, for which all the information is available and known to the decision makers, with all alternatives clearly defined [W. Edwards, 1954; Ref. 89]. In an other definition by Radford, “Tactical decisions are those that have little or no uncertainty associated with them, the cost and benefit can be easily quantified, the focus is on single objective, and often a single individual has the power to make decisions” [K. J. Radford, 1988; Ref. 90]. Models for conceptualizing tactical decision-making have been developed based on information processing. They highlight the analogy between humans and computers [A. Newell, J.C. Shaw and H. A. Simon, 1958; Ref. 91]. They work reasonably well for problems that are well-structured but are not useful in understanding ill-structured problem solving [D. N. Braunstein, G. R. Ungson, and P. D. Hall, 1981; Ref. 92].

Decision making from a strategic perspective is a relatively new area of research, and “although it has received a fair amount of attention, there is currently no well-accepted unifying theory driving research in this area" [H. Thomas and J. Mcgee, 1986; Ref. 93]. The reason is that "part of the problem has to do with the nature of strategic decision making itself. The broad, ill-structured, ambiguous nature of these decisions does not lend themselves easily to universally accepted operational definitions. Nor have criterion measures been developed to assess the effects of and on strategic decision making" [Theresa J. B. Kline, 1994; Ref. 87].

Most capital investment cases could be considered strategic. There are many uncertainties involved in the decision-making of capital investment. In the following paragraph, the capital investment evaluation models will be reviewed.

2.4.2 Current Capital Investment Practices

What techniques do US-based companies in the S&P's Industrial Index use in their capital investment practices? Researchers have been studying this since the 1970s through surveys. These surveys have been done by: Klammer in 1969; Gitman and Forrester in 1977 [L. Gitman and J. Forrester, 1977; Ref. 94]; Kim and Farragher in 1979 [S. Kim and E. Farragher, 1981; Ref. 95]; and Klammer, Boch, and Wilner in 1988 [B. Koch, T. Klammer, and N. Wilner, 1991; Ref. 96]. The results of these surveys in different time periods were tabulated by Farragher, Kleiman, and Sahu in 1999 [Robert T. Kleiman, Edward J. Farragher, and Anandi P. Sahu, 1999; Ref. 9]; see Table 1. These surveys are based on three categories: primary evaluation techniques; risk analysis techniques; and risk adjustment techniques.

What do these surveys say?

- About evaluation techniques:

The most used techniques are discounted cash flow, accounting ROI, and payback. Within these three techniques, discounted cash flow is most popular one across the time line. For example, based on the 1988 survey, 86 % of respondents use discounted cash flow, 4 % use accounting ROI, and 5 % use payback as their primary evaluation techniques. Based on data, more and more companies in S&P Industrial Index use discounted cash flow to evaluate their capital project.

- About risk analysis techniques:

According to surveys, few companies employ quantitative risk assessment, and those that do favor sensitivity analysis. The necessity for risk analysis is because capital projects more or less have a certain level of uncertainty. Having a certain level of uncertainty is common in any project.

- About risk adjustment techniques:

The most popular one is raising the required rate of return (ROR). Companies use this as a method for making a formal, quantitative risk adjustment.

Companies will not spend money on nothing. Especially in today's business environment, companies have to be responsive to stockholders. It is a well-accepted concept that companies should take action to justify their projects' risks.

These surveys focused on project evaluation and risk analysis tools, as opposed to the entire decision-making process. It is true that evaluation and risk analysis tools are important elements of the decision-making process. But investment success depends on the entire process. “The most significant deficiency of these studies is their limited focus on project evaluation and risk analysis tools rather than the entire investment decision-making process” [Robert T. Kleiman, Edward J. Farragher, and Anandi P. Sahu, 1999; Ref. 9]. “Focusing on the simple selection phase is myopic, and a more global approach is necessary to fully understand the capital budgeting process” [G. Pinches, 1982; Ref. 10].

Table 1: Surveys of Techniques Used in Capital Investment Practice by US-Based Companies in the S&P's Industrial Index.

	Klammer	**Gitman and Forrester**	**Kim and Farragher**	**Klammer, Boch, and Wilner**
Survey year	1969	1977	1979	1988
Number of Companies Surveyed	369	268	1000	468
Number of Respondents	184	110	200	100
Response Rate (%)	49.9	41.0	20.0	21.4
		% Using		
Primary Evaluation Techniques				
Discounted cash flow	57	74	68	86
Accounting ROI	26	28	8	4
Payback	12	10	12	5
Risk Analysis Techniques				
Mote Carlo simulation	13		10	12
Sensitivity analysis			23	57
Measuring covariance of project	3			1
Risk Adjustment Techniques				
Raising required ROR	21	44	19	40
Shortening payback period	10	13	14	19
Certainty equivalent		27	3	

Data source: Survey by Farragher, Kleiman, and Sahu, 1999

2.4.3 What Should Be Encompassed in A Capital Investment Evaluation System

As suggested by Gallinger in 1980 [G. Gallinger, 1980; Ref. 97], and Gordon and Pinches in 1984 [L. Gordon and G. Pinches , 1984; Ref. 98] activities that should be encompassed in a sophisticated capital investment system are: 1. Strategic Analysis; 2. Establishing investment goals; 3. Searching for investment opportunity; 4. Forecasting investment cash flow; 5. Risk-adjusted evaluation of forecasted cash flow; 6. Decision-making; and 7. Implementation of accepted opportunities post-audit performance.

In 1999, Farragher, Kleiman, and Sahu conducted a survey within 379 U.S. companies in the Standard & Poor's Industrial Index based on these activities [Robert T. Kleiman, Edward J. Farragher, and Anandi P. Sahu, 1999; Ref. 9]. The findings of this survey are:

1. Strategic Analysis

Corporate strategic factors are a very important component of most respondents' capital investment decision-making process. 93% of the responding companies conduct ongoing strategic analyses. And, of those companies, 94% expect them to identify the company's competitive advantages, and 97% expect them to indicate markets, products, and services for which the competitive advantages are most applicable.

2. Establishing investment goals

78% of the responding companies develop strategic investment goals. 92% specify a quantitative minimum required rate of return. 84% define the quantitative maximum acceptable risk.

3. Searching for investment opportunities

96% of the respondents search for and consider capital investment opportunities continually throughout the year. Only 4% wait until they prepare an annual capital budget. 62% of the respondents indicate that corporate strategic factors are more important than individual project return/risk factors when searching for investment opportunities.

4. Forecasting investment cash flow

60% of the respondents require that forecasters provide a formal linkage between corporate strategy and individual project forecasts. 61% of the respondents consider each project's holding period the forecasting period. 93% of the respondents forecast investment return on a cash basis or both a cash and an income basis. 55% of the respondents require a quantitative risk assessment and prefer sensitivity analysis and scenario (high-average-low) analysis.

5. Risk-adjusted evaluation of forecasted cash flow

Discounted cash flows techniques are the most popular. Most respondents, more than half, handle risk on an informal ad hoc basis. Within those, a formal, quantitative, risk-adjusted evaluation is required. 63% use risk-adjusted discount rates, and 37% adjust the forecasted cash flows.

6. Decision-making

When investment presents significant desirable strategic aspects but not good enough to meet the finance goals, keen management judgment is required. 57% of the respondents indicate that strategic factors are more important than financial factors when making the accept/reject decision. But only 45% will accept a capital investment opportunity that has positive strategic factors but a negative NPV.

7. Implementation of accepted opportunities post-audit performance.

No decision process is complete until it is reviewed, and its lessons are learned. 88% of respondents conduct post-audits regularly. 79% of respondents use post-auditing results to bring on corrective actions for poorly performing investments.

2.4.4 Large vs. Small Company Comparison

In 1997, Block presented the results of a study of project evaluation and risk analysis techniques used by small U.S. manufacturing companies [S. Block, 1997; Ref. 99]. In his study, a company is considered as a small company if it has less than $5,000,000 annual sales and fewer than 1000 employees.

The result of a comparison between large companies and small companies in their capital investment decision-making is listed as follows:

- Small companies are much less likely to use NPV or IRR when evaluating investment opportunities.
- Small companies are more likely to make formal quantitative risk adjustments.
- Both large and small companies prefer to change the required rate of return rather than adjusting the forecasted cash flow estimates.

2.4.5 Summary of Capital Investment Evaluation Models

- Capital investment decision-making should be an overall process, not just focus on evaluation and risk analysis tools.

"Effective allocation of company's capital resources is a key to corporate success. Most theorists hold that effective allocation can best be achieved with a sophisticated capital investment process. They post that a sophisticated process will enhance the probability of making good investment by helping ensure that corporate strategy is followed, that all investment opportunities are considered appropriately and consistently, and that the counterproductive political aspect of informal, ad hoc decision making is minimized" [Robert T. Kleiman, Edward J. Farragher, and Anandi P. Sahu, 1999; Ref. 9]. What is important is the comprehensiveness of the process, not just a focus on evaluation and risk analysis tools at the end of the process. "Focusing on the simple selection phase is myopic, and a more global approach is necessary to fully understand the capital budgeting process" [G. Pinches, 1982; Ref. 10].

- Capital investment should connect to corporate strategy.

To compete in today's fierce business environment, any company's resource allocation should accord to the company's strategy, especially for precious resource likes capital.

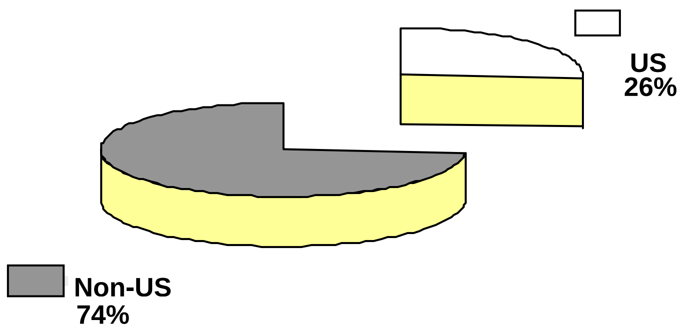
- Companies should have a formal capital investment decision-making process.

To ensure that company's strategies are followed, companies should have a formal capital investment decision-making process. And this capital process should cover the seven activities listed in 2.4.3.

3. PCB Fabrication Industry

3.1 Overview – The Importance of PCB in The Electronics and Computer Industry

"Printed circuit board manufacturing is a major component of the US economy, with worldwide sales of PCBs at approximately $21 billion in 1993 and a US contribution of 26%" [Office_of_Research_and_Development, 1995; Ref. 100] [S. Siddhaye and P. Sheng, 1998; Ref. 101]. See Fig. 1.



Data Source: Office of Research and Development,
U.S. EPA (EPA744R95005), 1993

Fig. 1 – Global Economics of PCB, US vs. Non-US

The application of PCB can be seen in the electronics and computer industries. "The implementation of electronic circuits into products involves several complex steps in design and manufacturing. One of the most common implementations is in Printed Circuit Boards (PCB's), which presents a low cost alternative in tooling and manufacturing over integrated circuits. In addition, PCB's can be altered to accommodate design changes after the product has been manufactured" [Sammy G. Shina and Anil Saigal, 1996; Ref. 102]

To make assembly easier, components of electronics/computer are put into modules. These electronics components are composed of electronic circuits. Some of the electronic circuits are very specialized and are grouped together in Integrated Circuits (ICs or chips). Each IC performs certain functions. It receives inputs from other ICs/chips and generates output for other ICs. To complete the desired functions, all ICs must be linked or wired to each other. To keep the wires that link all ICs from touching each other unnecessarily, the paths of all wires should be fixed in place and not until certain position should two wires will joint. PCB is to provide such a function. PCB is like highways to an enterprise with plants located in separate geographic locations for electronics and computer components. It provides fixed communication channels between ICs for electronics and computer components. Without communication channels, ICs would not be able to get input from other ICs/chips and send output to other ICs. In other words, without PCB, all ICs could not communicate to each other. As a result, the electronic component could not perform its functions.

"In electronics design, the trend is to integrate all functions into an IC. But ICs are still tracking Moore's Law. Increasingly difficult problems are cropping up as signals travel off the ICs, through their packages and across the PCB board. Thus, early prototyping and analysis of complex PCBs is becoming critical" [Charles H. Small, 1998; Ref. 103]. The PCB design becomes the focus of entire electronics/computer design process.

3.2 Business Models and Three Production Phases in the PCB Industry

There are three phases in PCB manufacturing, Design, Production, and Testing. Please refer to Fig. 2. The details of each phase will be studied:

Fig. 2 - Three Phases in PCB Manufacturing

In total, there are three business models in PCB manufacturing field, Original Equipment Manufacturing (OEM), Original Design and Manufacturing (ODM), and Integrated.

In the OEM model, customers take care of the PCB design and then send the final design to PCB manufacturer to be produced. And the PCB manufacturer takes care of the last two phases: Production and Testing. Please refer to Fig. 3. The input from customer to manufacturer is finalized PCB layout.

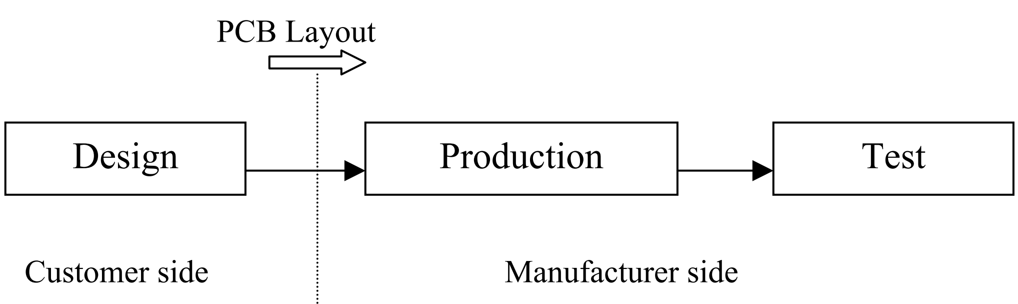


Fig. 3 - PCB Business Model - OEM Model

In the ODM model, customers send their requirements to a PCB manufacturer. The PCB manufacturer takes care of all three phases. Please refer to Fig. 4. The input from customer to manufacturer is the detail requirement for PCB.

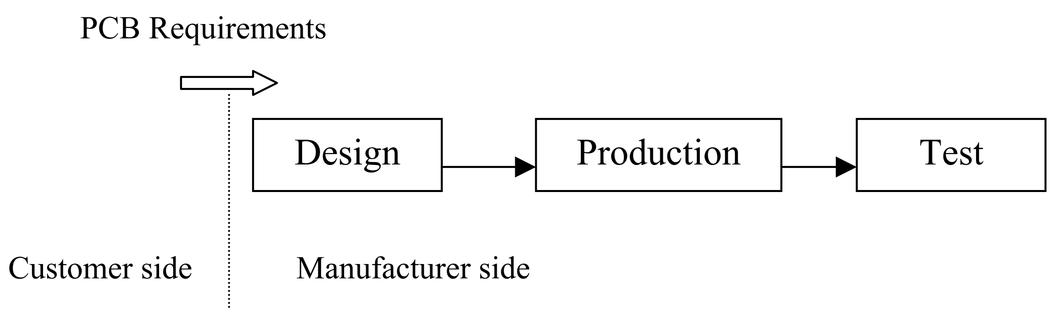


Fig. 4 - PCB Business Model - ODM Model

In the Integrated model, the customer and manufacturer are the same company. The customer, or manufacturer, has to work out the PCB requirements and take care of all three phases. Please refer to Fig. 5. The input will be the product requirements from the market.

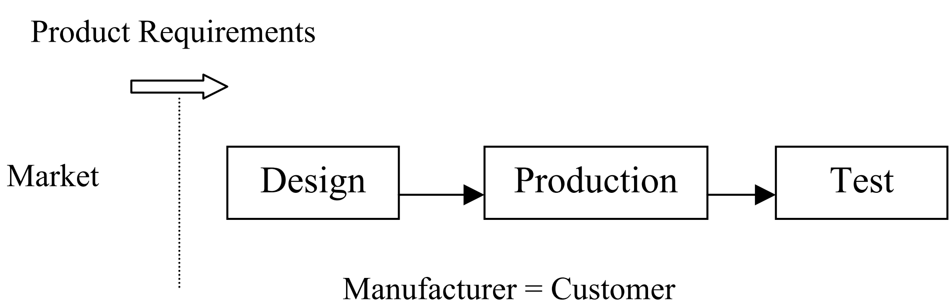


Fig. 5 - PCB Business Model - Integrated Model

Based on these three models, manufacturer performs different level of activities in PCB manufacturing, from PCB design to testing. The process detail in each phase will be studied in this research.

3.2.1 Design

The design phase is the most knowledge-intensive phase. The design of PCB combines of electronic design, mechanical design, fabrication selection, EMI/RFI certification, Quality Assurance (QA), prototype testing, and redesign. The design phase is the most critical phase of the three phases. See the design-process flow chart in Fig. 6. In this phase, major costs are determined. The quality of PCB is also mainly affected in this phase. To design a PCB one must: 1. Study product requirements; 2. Pick ICs and other electronic parts; 3. Surface planning; 4. Pre-layout the PCB; 5. Prototype; and 6. Prototype test. If the test results are not satisfactory, repeat steps 2 to 5. Currently, there are many computer-aided PCB design software tools available on the market.

Study product requirements

The product requirements may come externally or internally. Those that come externally could be user suggestions, results of market surveys, or required by major customers. Those that come internally could be, for example, that product engineer want to improve the performance of current product, add new features to the current product, or design a whole new product. All these requirements should be studied carefully. The circuit-logic design of PCB is based on these requirements.

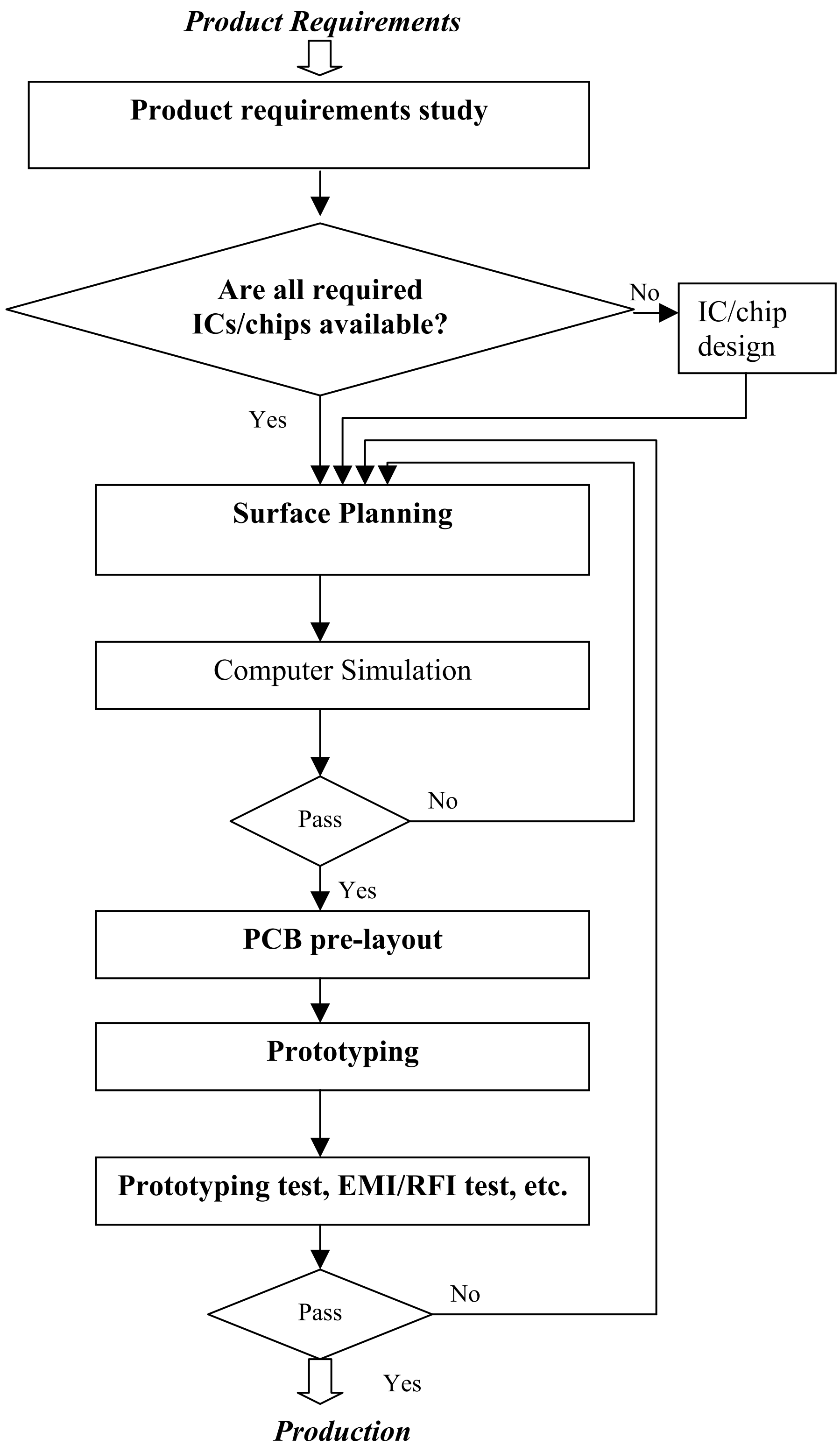


Fig. 6 – Flow Chart of PCB Design

Picking ICs/chips and other electronic parts

After the product-requirements study is done, engineers start to search for the available ICs that meet product requirements. Those ICs that are available on the market are called “commodity ICs”. In some cases, some ICs in design are not available. Engineers have to decide whether to embed the required functional circuit in the PCB circuit or to design these new ICs.

Surface Planning

Most of the PCBs are to be put in a limited space. Thus, the area of the PCB surface is limited. In order to put all the required ICs on the PCB surface, engineers have to go through detailed surface planning. Surface planning is one of the critical tasks in PCB design. It will affect the mechanical characters, thermal properties, and electronic properties of PCB. For example, if two ICs are too close, there will be “cross talk” between them. “Cross talk” will result in unnecessary electronic noise that will cause unexpected I/O operations of the product. Major tasks of surface planning are: a. dimension study; b. pin-connection study; c. thermal properties study; and d. electronic properties study. Please refer to Fig. 7. The purpose of surface planning is to find a geometry-location balance among all ICs based on those criteria listed above. Currently, there are many software tools available on the market that will help engineers’ surface planning. These kinds of software will also provide design guidelines for engineers.

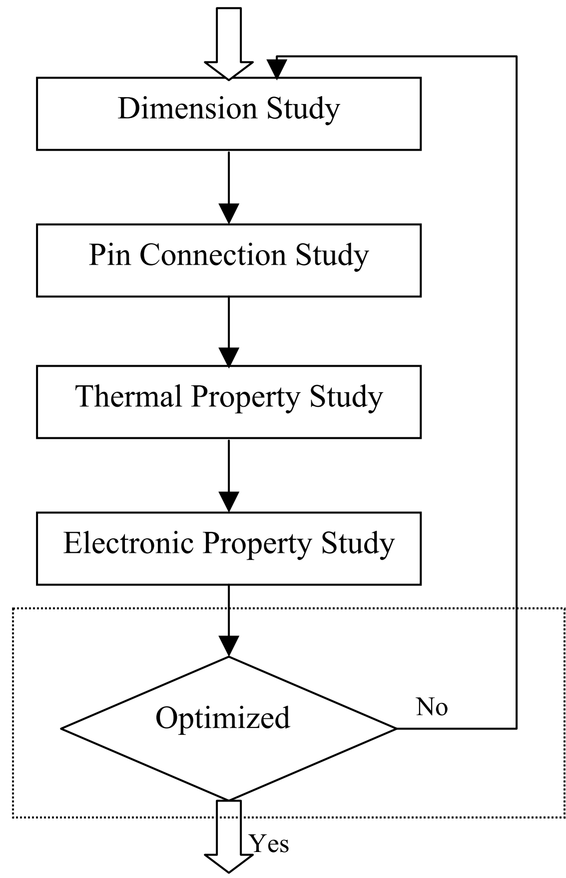
a. Dimension study

"More than half of the board designs have 10-50 ICs on them with package counts over 500" [Charles H. Small, 1998; Ref. 103]. To put all these ICs on the limited PCB surface, the physical dimension of the ICs and its position in the PCB should be carefully studied. Doing this not only to prevent physical space conflict but also influences the thermal effect, electronic effect, wire routing, and the operation of the surface mounting of these ICs on PCB. For example, if a heat-sensitive IC is put close to a transformer, it will suck heat from transformer and generate "heat noise" that will result in an unexpected I/O operation. Another factor that will cause unexpected I/O operation is the electronic noise. Most electronic noise comes from "cross talk" between wires that connect ICs. Both kinds of noise sources can be avoided mainly by separating with a certain geometric distance. The result of this process is the geometry location-data of all parts. The result will be input to a computer simulation for final study.

b. Pin-connection study

All ICs communicate with one other via pins in their IC packages. The products' functions are performed via a certain sequence of signals through related ICs. Based on these sequences, engineers decide how to route the wires that connect ICs. The wire configuration is then printed on plastic board to form PCB. Pin connection study is one of the most intellective tasks in PCB manufacturing. The result of this process will be input into a computer simulation for wire routing and circuit logic test.

Picking ICs/chips and other electronic parts



PCB Pre-Layout

Fig. 7 – Flow Chart of Surface Planning Process

Note: Processes that included in dashed rectangle block is computer simulation. It depends on company's facility. Only for those companies that have computer software tools to simulate the design will have this process. Otherwise, the process loop back will comes from Prototype Test and EMI/RFI Test

c. Thermal-Properties Study

The thermal problem is one of the tough problems in PCB design. Today, nearly all the digital ICs are high-speed IC. The high speed of electronic "On/Off" switching within the IC will generate heat. Heat has to be radiated out from the IC's surface and PCB. If the heat is accumulated within the IC, the temperature of the IC will increase. This will result in the IC's performance degrading. In some cases, it burns the IC or PCB. This could be seen in high-speed CPUs in PCs. If heat accumulates on the PCB without proper handling, it not only degrades the whole product performance, it creates thermal noise too. As mentioned earlier, thermal noise will cause unexpected I/O operations that will result in product malfunction. The result of this process will be input into a computer simulation for final study.

d. Electronic-Property Study

The electronic properties, like how close two related ICs have to be to cause "cross talk" between them will be studied. How far apart two wires need to be in order not to "cross talk" to each other is also to be studied. These depend on the amplitudes of the signals generated by the ICs. For commodity ICs, the IC manufacturer provides related information. For customer ICs, engineers have to work it out themselves. These data are required for computer simulation.

Pre-Layout of the PCB

The pre-layout PCB process is to prepare everything for prototyping the PCB. Some companies combine this process with surface planning via an integrated computer system. After surface planning, it goes to prototyping directly. In those who do not have such facility, engineers have to draw the circuit chart. Then, based on their experience and information from previous process, engineers have to go though smart trial and error process "manually" to optimize the design.

Prototyping

This process is to create samples based on the PCB pre-layout. These samples are to be tested as required in the Prototyping Test process. Those companies that do not have the capability to process those tests, such as the EMI tests, required by regulations, have to send their samples to certified agents to be tested.

Prototype Test, EMI/RFI test, etc.

This process is the final process in the design phase. The circuit logic is to be tested physically, not with simulation. All the regulation-required tests are to be conducted here and passed. Normally, a number of redesigns are necessary before all tests are passed.

3.2.2 Production or Fabrication

PCB fabrication typically involves a series of processes divided into pre-preg fabrication, inner-layer circuitization, and outer-layer circuitization. See Fig. 8. [P. Sheng and S. Siddhaye, 1998; Ref. 101]. This process model is for a two-layer PCB. For multi-layer PCB, Outer-Layer Circuitation is repeated.

Pre-Preg Manufacturing

Pre-Preg manufacturing is the production of lamination sheets to produce copper clad cores.

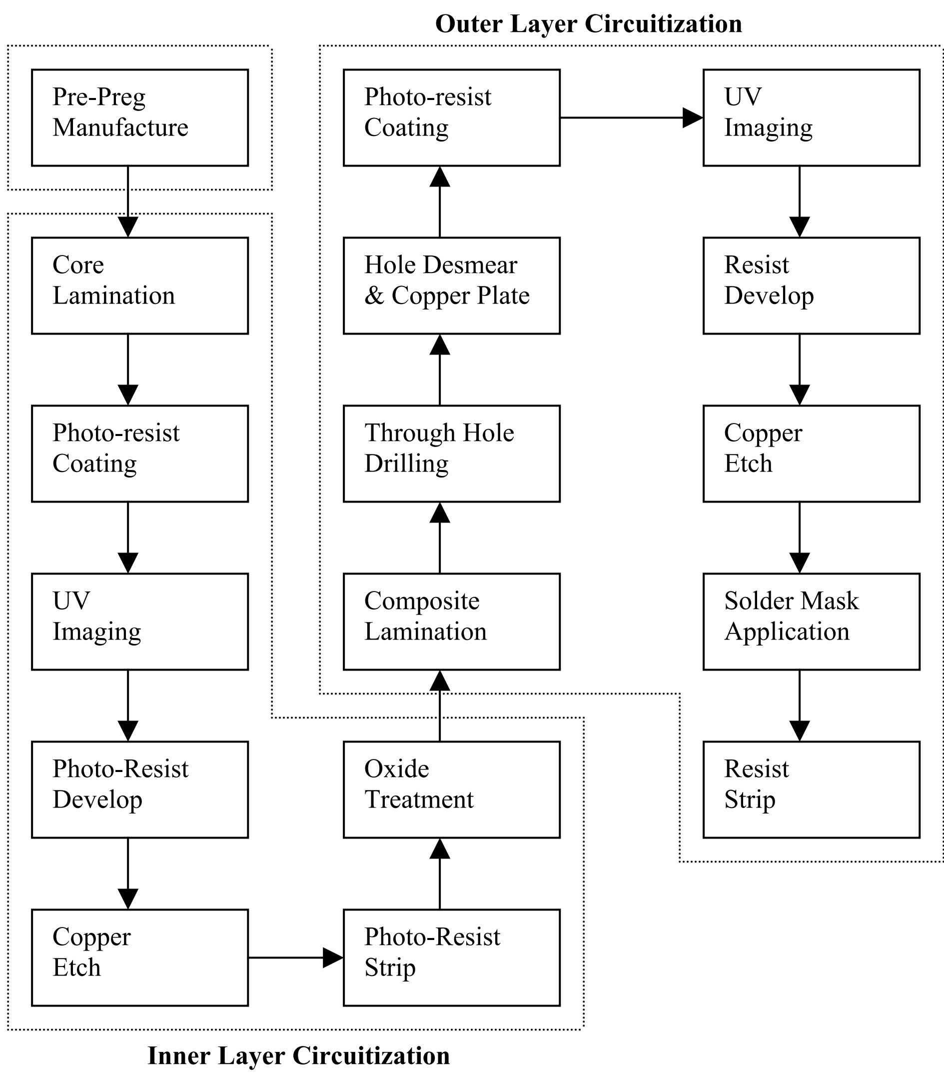


Fig. 8 – Process Steps in PCB Fabrication

Inner-Layer Circuitization Process

Core Lamination

Core lamination is a thermal process in which the bare pre-preg sheets are laminated with copper on both sides to produce clad cores [C. F. Coombs, 1995; Ref. 104] [J. Fisher, 1995; Ref. 105]. This process includes following sub-processes in sequence. See Fig. 9:

1. Core formation – a number of preg sheets are stacked with copper foils on both sides to form cores;
2. Core-stack formation – a number of cores are stacked together with an aluminum sheet between every two cores to form a core-stack or book;
3. Lamination Preparation – a number of core-stacks are stacked in between the steel platens of the lamination press;
4. Heating and Pressing – the stacked core-stacks are heated by hot-water circulation and pressed for about two hours. After this, the stacked core-stacks will sit for a period of time to be completely cured; and
5. Trimming – the improperly laminated edges of cores are trimmed. After this process, all cores are ready for Photo-Resistant Coating.

Photo-Resistant Coating

Photo-resist coating is the first step in circuitization of the inner layers. In this step, both sides of the blank copper-clad core are coated with a layer of photo-resistant and exposed to UV light through an artwork film [C. F. Coombs, 1995; Ref. 104] [J. Fisher, 1995; Ref. 105]. This process includes the following sub-processes in sequence. See Fig. 10.

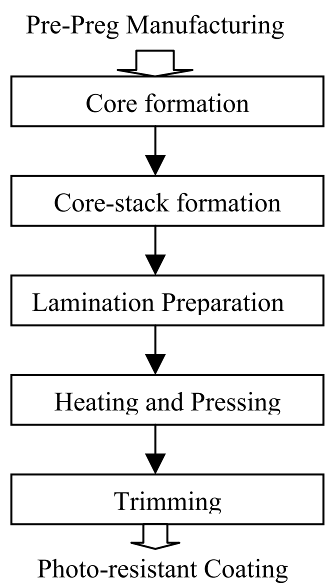


Fig. 9 – Flow Chart of Core-Lamination Process

1. Blank-core cleaning – a blank core is cleaned with water. A clean core surface will help in placing the resistant film onto the copper.
2. Core coating – photo-resistant film is rolled on the core. Photo-resistant film has a polyolefin sheet on one side and a mylar sheet on the other. Before photo-resistant film is rolled onto the core, the polyolefin sheet is removed. The mylar sheet will be removed after UV Light Exposure and before Resistance Developing.

UV Imaging

The photo-resistant coated core is exposed to UV light to polymerize the photo-resistant with a circuit image pattern.

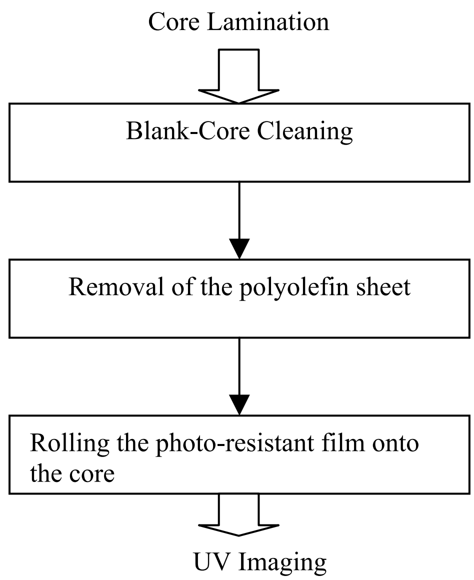


Fig. 10 – Flow Chart of Photo-Resistance Coating Process

Photo-Resistance Development

After the pattern is imaged through UV exposure and selective polymerization, a developing solution removes the unpolymerized resist and exposes the copper underneath [C. F. Coombs, 1995; Ref. 104]. This process includes sub-processes that occur at the same time. See Fig 11:

1. Polymerized photo-resist swelling – the developer solution is diffused into the photo-resist film and swells the photo-resist; and
2. Unpolymerized Photo-Resist Removal – the carboxylic-acid binder of unpolymerized photo-resist is neutralized by the developer solution to form water-soluble carboxylic salts, then breaks apart. The unpolymerized photo-resist was also ripped off by the pressured developer solution.

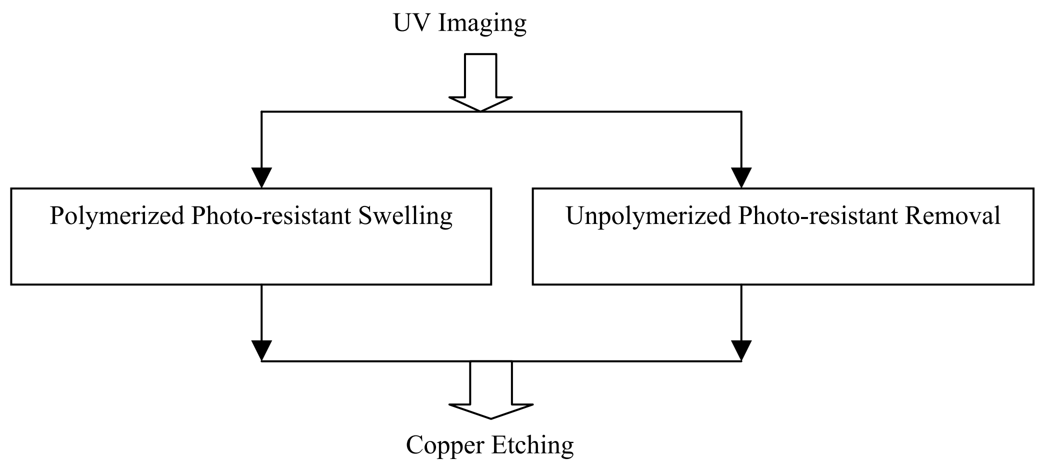


Fig. 11 – Flow Chart of Resistance Developing Process

Copper Etching

After the cores go through the Resistance Develop process, the copper is exposed at the non-circuit areas. The copper of these exposed areas will be etched away. The Copper Etching process includes the following sub-processes. See Fig. 12:

1. Rinsing – Cores are moved to the rinse station to wash away the developer solution and be dried; and
2. Exposed Copper Removal – The removal is done in the etching chamber. The pressured etchant solution is sprayed onto cores from top to bottom via nozzles. The exposed copper is removed chemically.

Photo-Resistant Stripping

The polymerized resistant that remains on cores will be removed in this process. Cores will be rinsed with acid to remove cuprous chloride residues, then rinsed with water to remove acid. After rinsing, cores are moved into the stripping chamber to remove the polymerized resistant [P. Sheng and S. Siddhaye, 1997; Ref. 106]. The in-sequence sub-processes of Photo-Resist Strip are as follows. See Fig 13:

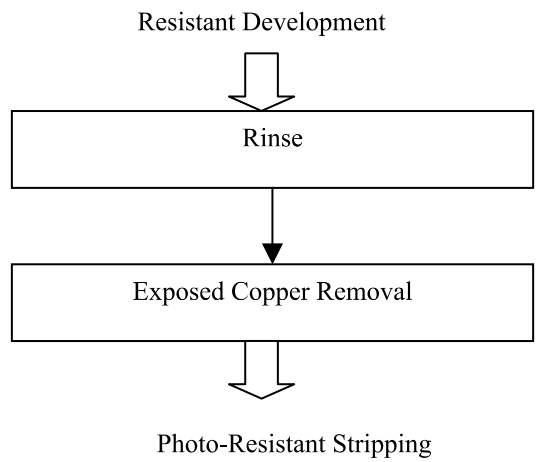


Fig. 12 – Flow Chart of Copper Etching Process

1. Acid Rinse – Cores are rinsed with acid to remove cuprous chloride residues;
2. Water Rinse – Cores are rinsed with water to remove acid; and
3. Stripping – Stripper solution diffuses into the polymerized photo-resistant film and swells it. The swelling will cause a rupture of the photo-resist film. After the rupture, the photo-resistant skins come off the core.

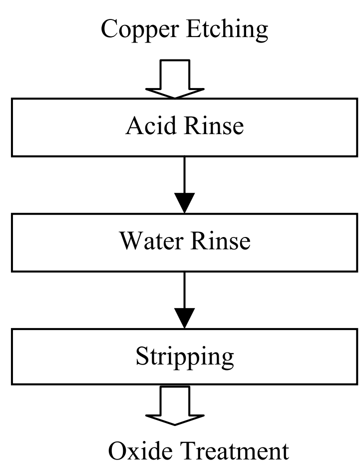


Fig. 13 – Flow Chart of Photo-Resistance Stripping Process

Oxide Treatment

The primary purpose of the oxide treatment is to remove oil and other dirt from circuitized cores and form a thin layer of crystalline copper oxide to aid in adhesion during lamination [P. Sheng and S. Siddhaye, 1997; Ref. 106]. This process includes the following sub-processes. See Fig. 14:

1. Cleaning – Cores are cleaned with special detergent to remove the dirt and oil that remains on them;
2. Water Rinsing – Cores are rinsed with deionized water. Normally, there will be number of water rinses to go through. Each rinse process is done in a different tank;
3. Copper Etching – This process is to etch a very thin layer of copper to expose pure copper. Cores are etched in an acidic sodium persulfate tank [P. Sheng and S. Siddhaye, 1997; Ref. 106];
4. Acid Neutralization – This process is to neutralize residual acid. Cores are to be rinsed with water, then put into an alkaline bath, and then rinsed with water;
5. Oxidization – This process is to use oxidizing agent, such as sodium chlorite, to oxidize copper; and
6. Copper-Oxide Reduction – A very thin layer of copper oxide will be reduced to copper via passing through a “reducing tank.”

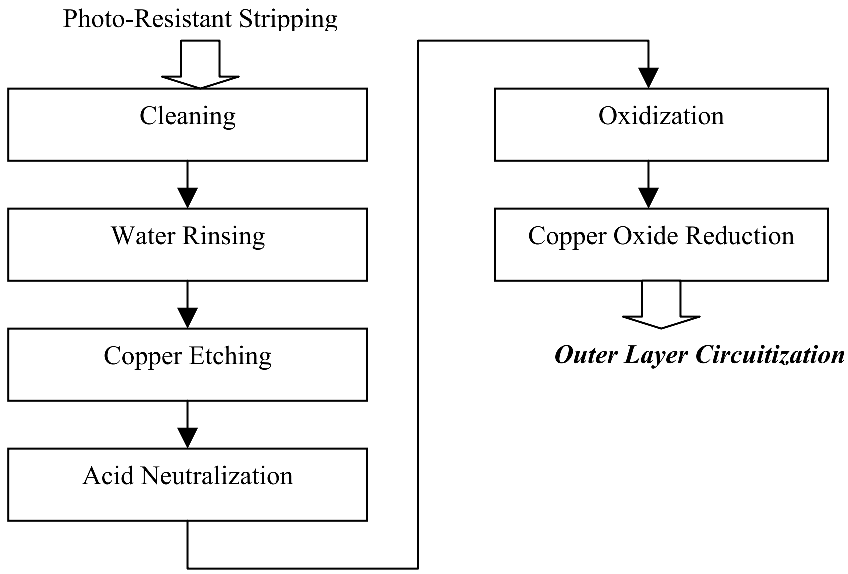


Fig. 14 – Flow Chart of Oxide-Treatment Process

Outer-Layer Circuitization Process

Composite-Lamination

Cores are laid and laminated to form a panel. Panels are stacked to form a book. This process includes following sub-processes [S. Siddhaye and P. Sheng , 1997; Ref. 106]. See Fig. 15:

1. Panel Formation – The circuitized cores will be stacked with a B-stage pre-preg sheet between them. Then the pre-preg sheets and copper foil will be placed on both sides of the panel to form the outer layers;
2. Book Formation – A number of panels are stacked with planishing stainless-steel plates to form a book, then pressed.
3. Curing – Books will go through a heat cycle to cure the separator pre-preg sheets within panels and supporting pre-preg sheets of outer layers;

4. Trimming – After curing, the panels will be removed from the press. The unevenly laminated edges will be trimmed to remove the uneven portion.

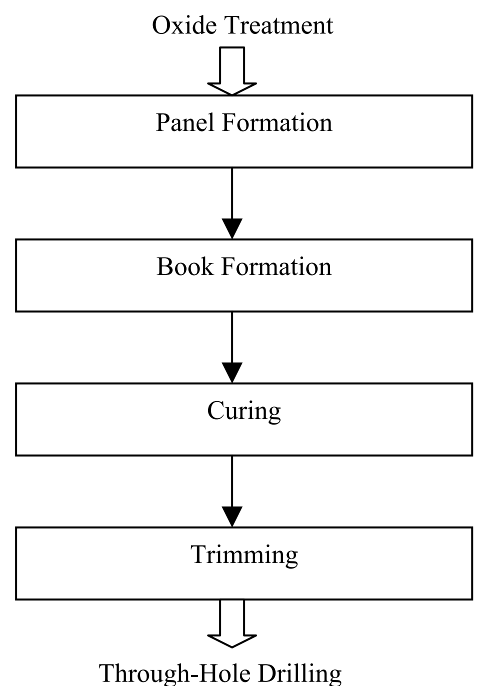


Fig. 15 – Flow Chart of Composite-Lamination Process

Through-Hole Drilling

As the name indicates, this process is to drill through holes. Through holes have different diameters. They are to hold the panel while it is processing, serving as attachment points to hold the board in an enclosure, conduction paths between circuit layers, and attachment points for connectors.

Hole-Desmear & Copper-Plate

This process is to remove the melted epoxy resin that is created during the hole-drilling process. The melted epoxy resin along the hole wall creates an isolating barrier to the inner-circuit copper. After the desmearing, a thin layer of copper will be deposited on the hole wall . This Process includes the following subprocesses. See Fig. 16.

1. Desmearing – Panels pass through a sweller solution. The sweller solution, contained in a tank, will diffuse into epoxy and swell it. Then, panels pass through a permanganate solution that will dissolve the swollen epoxy [P. Sheng and S. Siddhaye, 1997; Ref. 106];
2. Panel Cleaning – Panels are cleaned with an alkaline cleaner;
3. Micro-Etching – A thin layer of copper is etched away with acidic sodium persulfate from entire panel to expose the virgin copper.
4. Chemical Plating – Panels are catalyzed in an activator-solution tank to create active sites on walls of holes. Then, a thin layer of copper will be deposited, in an alkaline-chelated copper-reducing solution, on the walls of holes on panels [P. Sheng and S. Siddhaye, 1997; Ref. 106];
5. Electro-Plating – Panels are electro-plated in an acidic copper sulfate solution. The entire panel will be plated with uniform layer of copper; and
6. Rinsing and drying – After electro-plating, panels are rinsed with water and air-dried.

Outer-Layer Photo-Resistant Coating

Same as inner-layer Photo-Resistant Coating.

UV Imaging

Same as inner-layer UV imaging.

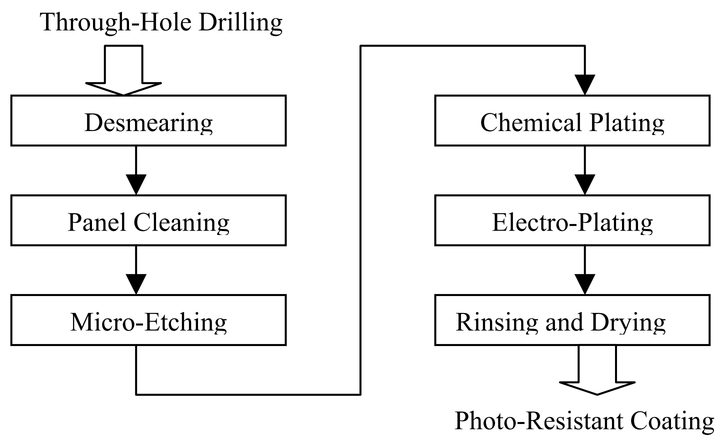


Fig. 16 – Flow Chart of Hole-Desmear and Copper-Plate Process

Resistance Development

Same as inner-layer Resistance Development.

Copper Etching

Same as inner-layer Copper Etching.

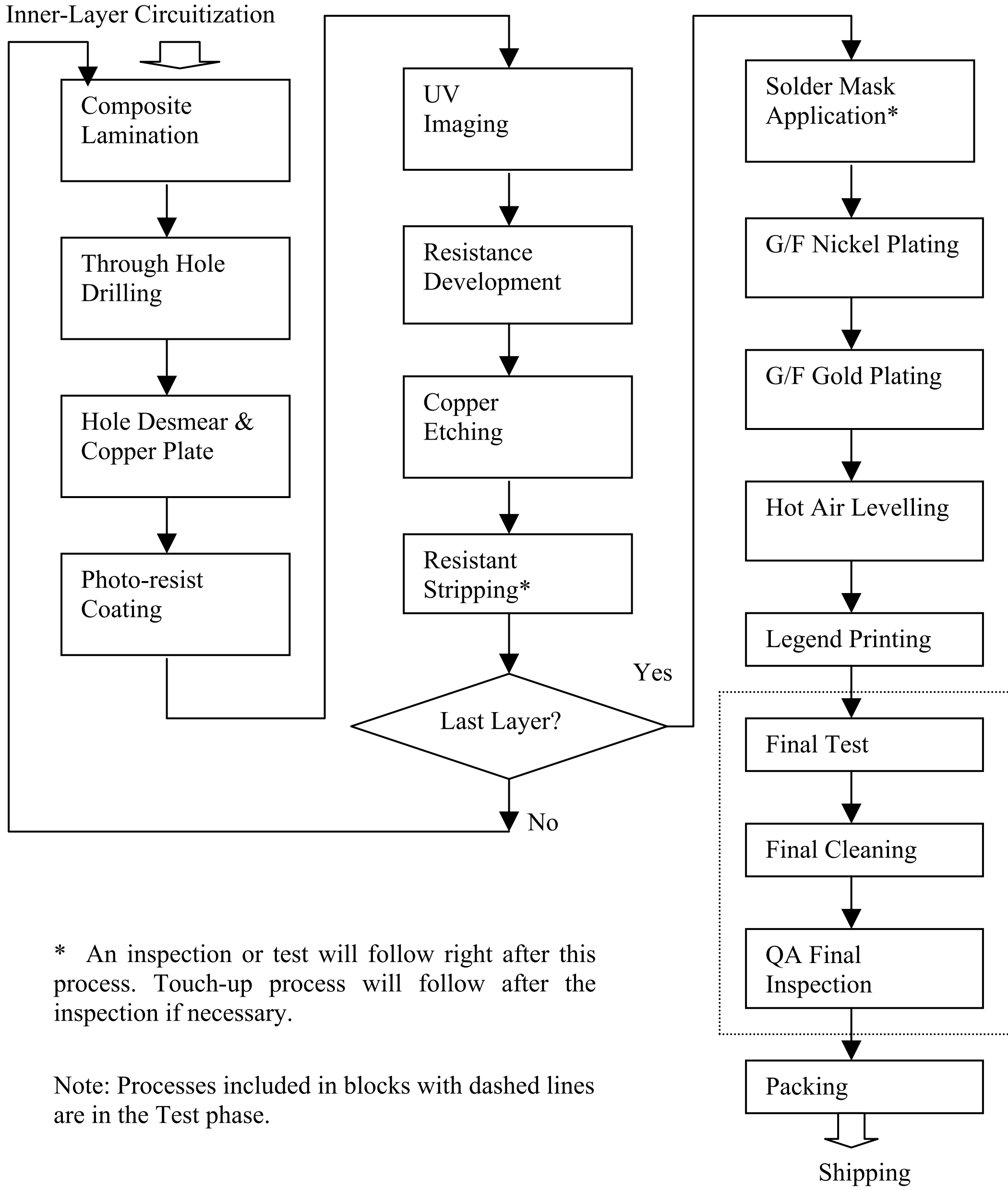
Note: For multi-layer PCBs, the outer-layer circuitization processes listed above, which is for two-layer PCBs, will be repeated through the last outer layer. See Fig. 17.

Solder-Mask Application

Solder mask application is used to coat panels with a polymer to protect the area that does not need soldering [S. Siddhaye and P. Sheng, 1997; Ref. 106]. This process includes following sub-processes. See Fig. 18:

1. Scrubbing – Panels are scrubbed with pumice slurry to remove oil and dirt;

2. Solder-Mask Material Coating – There are two ways to coat the solder mask material, curtain coating and screen coating. In curtain coating, panels pass through a curtain of liquid solder-mask polymer. In screen coating, solder-mask polymer is applied to panel through a screen-printing operation;
3. Heating and Drying – After the panels are coated with the solder mask material, they pass through an oven to be heated and dried;
4. To-be-soldered Area Solder Mask Removal – Panels are moved onto a expose-develop line, and solder masks on contact points, through holes, and SMT pads are removed.
5. Solder-Mask Curing – Panels are thermally cured for epoxy and UV-light cured for acrylic;
6. Legend Printing – A legend is printed with UV-curable ink on each board.
7. Cutting – Individual boards are cut from the panel with a router.



* An inspection or test will follow right after this process. Touch-up process will follow after the inspection if necessary.

Note: Processes included in blocks with dashed lines are in the Test phase.

Fig. 17 – Flow Chart of Industry Outer-Layer Circuitization Process

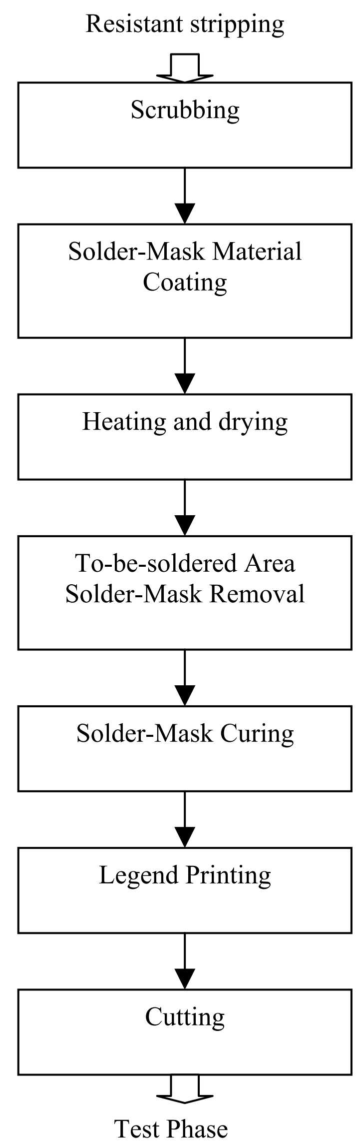


Fig. 18 – Flow Chart of Solder-Mask Application Process

3.2.3. Test

Currently, many PCB manufacturers implement in-process testing. The in-progress boards are tested in different processes. The in-process test gives the company an opportunity to fix the defects in early process. For example, in the photo-resistant stripping process, at the end of the process, a test will follow. The test is to check whether there is any broken circuit. If there is a broken circuit, a touch-up process to fix it will follow. Some tests can only be done in final phase. Circuit functionality is one of them. Some tests are to be done by special government agencies, like FCC. Most companies have a final quality assurance (QA) inspection before the products are shipped.

4. Research Methodology

Capital-investment evaluation models will be built to study the impact of QFD and ABC on the capital investment decision: General Model; QFD Model; ABC Model; and Model with QFD and ABC (Integrated Model). The General Model will be the base model. The QFD and ABC Models will be benchmarked against the General Model to study the impact of QFD and ABC. Lastly, the Model with QFD and ABC will be used to determine whether there is any synergy effect when QFD and ABC are integrated into capital-investment decision-making process. The model benchmarking and synergy effect study will be done via interviewing the members of the Expert Panel in this research.

4.1 Knowledge Acquisition

There will be two methods used in this research to acquire the relevant knowledge. The first one is literature review. The second one is interview with expert.

4.1.1 Method 1 – Literature review

The first method of knowledge acquisition is through a review of literature. The literature review will be done on the following topics: 1. Decision-making models; 2. Capital-investment decision models; 3. Quality function deployment; 4. Activity Based Costing; and 5. The PCB fabrication industry.

The literature was used with other sources in this study to furnish the knowledge of capital investment evaluation models in the PCB fabrication industry. The results of the literature review are contained in chapter 2.

4.1.2 Method 2 – Expert Interview

The second method of knowledge acquisition is interviews with experts. A pilot interview of experts will be conducted before the actual interview of the expert panel. The interviews with experts are to: 1. Verify whether the related material is adequate to reveal the related topics to the interviewees; 2. Verify whether the survey questionnaires are adequate for validating the models; and 3. Acquire related knowledge of industrial experts for material modification. The interviewee was an individual recommended by leading experts in this field such as Dr. Donald Merino and Dr. Hosein Fallah.

The interview was conducted face-to-face. The interviewee was presented with the model description in PowerPoint slides, then asked to fill out the survey questionnaires for that model. See Appendix A for the presentation package and appendix B for survey questionnaires in detail. To minimize the effects of prolonged research, the time for the interview is limited at one and half hours.

The result of the pilot interview and suggestions made by the interviewee will be used to modify the material used in the interview of members of the Expert Panel.

4.2 Building Capital Investment Evaluation Models

Based on the literature review, there is no capital-investment evaluation model that encompasses QFD and ABC specially built for the PCB industry. See attachment for literature search results. The four models in this research were built based on the knowledge from the literature review.

4.2.1 Proposed General Model

"A major engineering and construction firm recently studied the relationship between the decision process for capital investment and the expenditure of funds. They found that approximately 80% of the capital cost of a plant is locked in on completing the conceptual design"[Robert L. Steinberger, 1995; Ref. 107]. The PCB manufacturing industry has a similar situation. In today's highly competitive environment, investments become a strategic weapon in gaining competitive advantage. "In today's economy, successful manufacturing firms must be strategically poised to take advantage of constantly changing market opportunities and defend against competition" [Robert L. Steinberger, 1995; Ref. 107]. In 1992, Proctor and Canada gave a detailed classification of capital budgeting methods that conventionally focus on the economic costs and benefits associated with a potential capital-investment project [M.D. Proctor and J.R. Canada, 1992; Ref. 108]. These methods typically ignore qualitative factors [S.B. Stokdyk D.S. Remer, and M. Van Driel . 1993; Ref. 109]. These methods also fail to account for multiple non-monetary goals that are hard to quantify [C.Y. Baldwin, 1991; Ref. 110]. The shortcomings of these methods are more easily seen when they are applied to manufacturing companies that produce special products in a very competitive market niche. “The inappropriateness of the traditional techniques in this context poses a serious problem for most manufacturing managers, as they vie for market share in a new, more competitive environment ” [Fariborz Y. Partovi, 1999; Ref. 8].

“In recent years, several multi-attribute models that integrate business strategy and capital allocation have been introduced. These models fall into four main groups [Fariborz Y. Partovi, 1999; Ref. 8]: multi-attribute utility models [M.R. Walls, 1995; Ref. 111]; linear programming-based models [Y.K. Son and C.S. Park, 1998; Ref. 112]; expert system models [I. Cil and R. Ever, 1998; Ref. 113]; and analytic hierarchy process (AHP) models [Paul R. Kleindorfer and Fariborz Y. Partovi, 1990; Ref. 7] [T.F. Monohan, M.J. Liberatore, and D.E. Stout, 1992; Ref. 114]. Each model group has its advantages and disadvantages. Among these models, AHP is most widely accepted to evaluate capital-investment alternatives that are strategic and difficult to quantify [W.G. Sullivan and J.R. Canada, 1989; Ref. 115] [W.G. Sullivan, J.R. Canada, and J.A. White, 1996; Ref. 116]. The advantages of AHP include a structured approach, combining customer wants and internal objectives of the company to evaluate alternative projects, flexibility in criteria selection, and no requirement of a massive accounting and measurement system. The disadvantages of AHP include ignoring the direct assessment of the competitor’s status and its importance in selecting capital projects [Fariborz Y. Partovi, 1999; Ref. 8]. Is AHP right for the PCB industry? What factors should be considered for the PCB industry to make an investment decision? What processes does making an investment decision take? Before we answer such questions, let us take one level higher. What triggers a need for investment? Should it be a strategic or tactical movement? Here, the author proposes an investment decision process model. See Fig. 19.

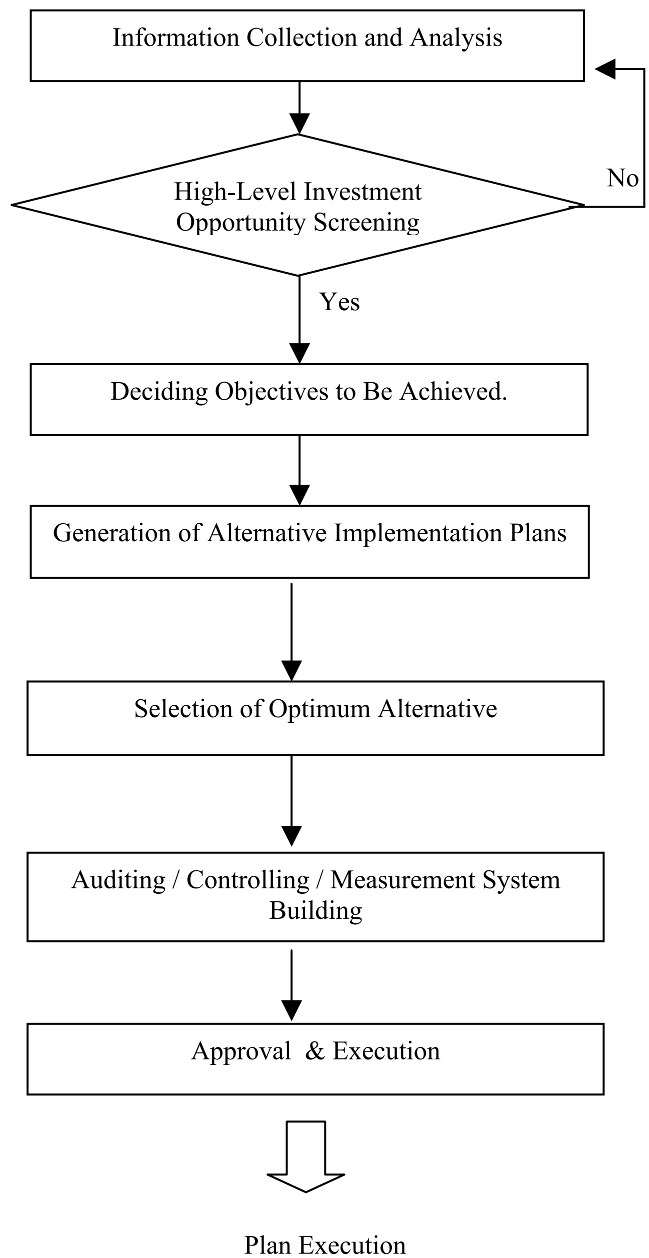


Fig. 19 – Flow Chart of the General-Model

Model Description

Information Collection and Analysis

The information collection and analysis process is critical for companies. The information to be collected includes new technologies, markets, and operations. Then, they will be analyzed to see whether and how they will impact the company. See Fig. 20.

- New Technology Information

Companies should always keep an eye out of new technologies. New technologies could change a company's operation flow and product lines. New technologies could also bring revolutions to industries. The internet is a typical example.

- Market Information

Market information about what percentage of the whole market your company has and how much it wants to increase in the future is one of the major driving forces that trigger a company's investment activities. The new market is also one of the major driving forces. A company could invest either in new technologies or existing technologies to increase production. Investments that are driven by the market are very critical to industries with a short product life cycle.

- Operation Information

Operational needs are investment driven forces too. Increasing production capacity or product quality is a major trigger of these operation needs. Recently, investing in Information Technology (IT) to help companies gain competitive power becomes a hot issue in every industry. Computer systems like Enterprise Resource Planning (ERP), Supply Chain Management (SCM), and Customer Relationship Management (CRM) help companies to increase their quality of operations.

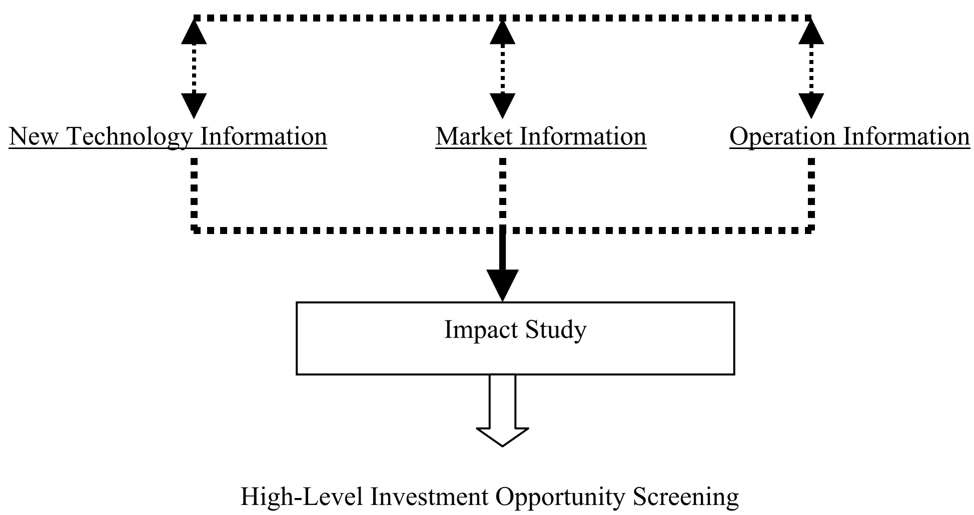


Fig. 20 – Flow Chart of Information Collection and Analysis Process

- Impact Study

Once the relevant information is collected, a study of how they will impact your company or even the whole industry is necessary. The results of this process will be used in later processes.

High-Level Investment Opportunity Screening

This is a critical process to a company. The quality of the results of the Impact Study and this process will impact the future of a company. With input from the impact study, economic and non-economic study will follow. In this process, whether to make an investment will be decided. A list of how the collected information will impact the company will be made based on the results from the Impact Study process. A list of how the company could respond to these impacts will be generated. With these two lists, economic benefits and strategies benefit will be studied. A "pass" or "fail" decision will be made based on the study results. See Fig. 21:

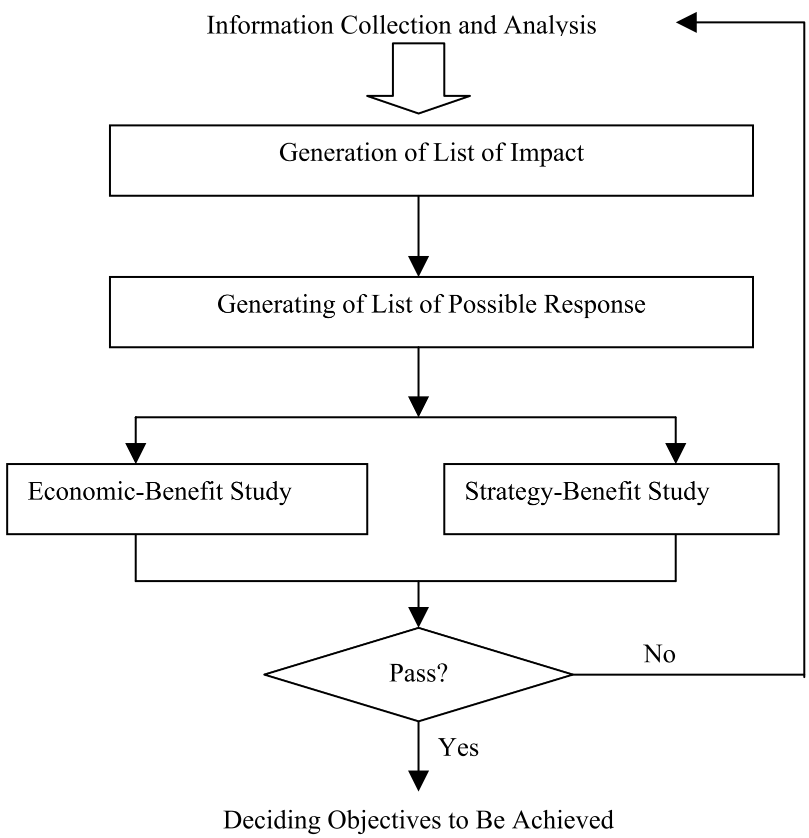


Fig. 21 – Flow Chart of High-Level Investment Opportunity Screening Process

Deciding Objectives to Be Achieved

Once past the High-Level Investment Opportunity Screening process, a set of objectives to be achieved in this investment project will be generated. These objectives could be market objectives, production objectives, or strategy objectives. All these objectives should also be consistent with a company's long-term or short-term objectives. These objectives could be demands from customers, too. At the end of this process, these objectives will be set in order of priority. See Fig. 22:

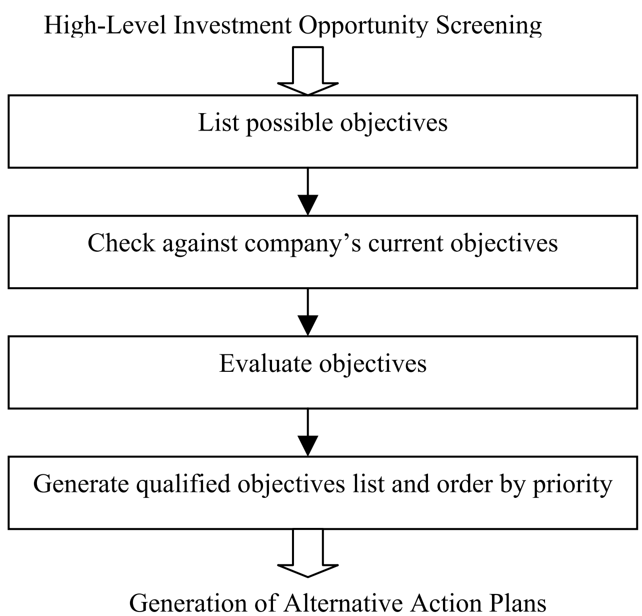


Fig. 22 – Flow Chart of Deciding Objectives to Be Achieved Process

Generation of Alternative Implementation Plans

Based on the generated qualified action plans from the previous process, alternative implementation plans that could achieve these action plans will be generated. The implementations plans are high-level ones such as outsource the action plan, etc.

Selection of Optimum Alternative

Once alternatives are generated, the one that can most maximize project objectives is selected.

Auditing / Controlling / Measurement System Building

Once the best action plan is selected, a measurement system should be built to monitor progress.

Approval & Execution

After the best one is selected, it has to be approved by relevant parties in the company, and then executed.

4.2.2 Proposed QFD Model

Fig. 23 shows the overall road map for implementing QFD into the decision-making process. It shows the decision-making processes relate to the QFD matrix. For example, the High-Level Investment Opportunity Screening will use the QFD phase-3 matrix. It uses the product characteristics to process characteristics relationship to check whether the investment target can improve the product quality or process efficiency.

Model Description

With QFD, users could easily see how the production processes relate to quality. This model mostly follows the General Model, except in certain process, where QFD provides the necessary information. In the following paragraphs, the author will show a road map of how to implement QFD into decision-making processes and explain each step in detail.

The following are the steps for implementing QFD into the decision-making process:

1. QFD preparation.

   Using the identified relationship between the quality and production processes as a guideline to identify key processes for quality improvement or production efficiency;
2. Using the results from step 2 as a guideline to screen investment opportunities;
3. Deploying the screened candidates in step 3 into detailed production processes; and

4. Combining the cost information and the results from step 4 to see how cost-effective the investment will be.

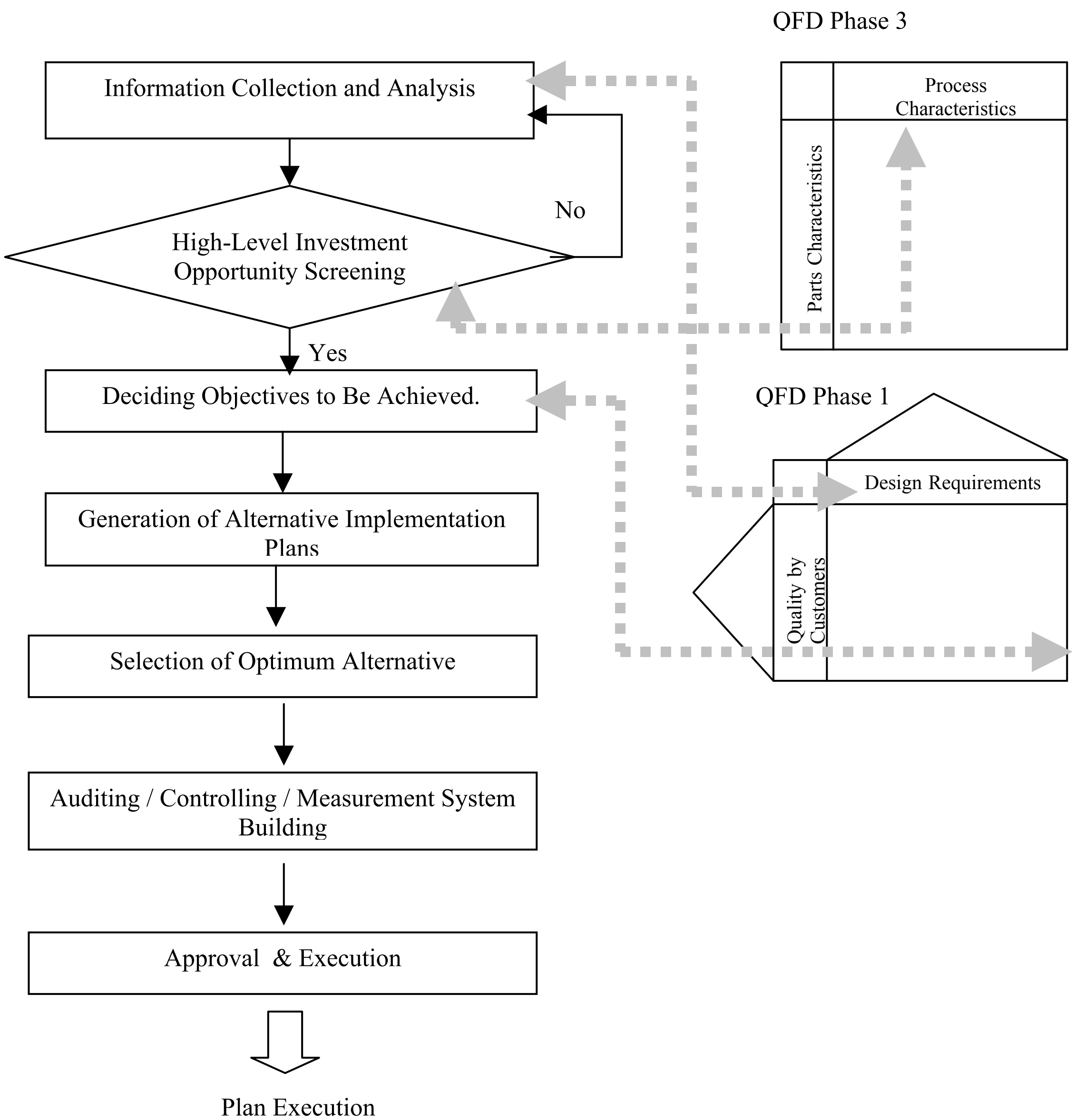


Fig. 23 – Flow Chart of the QFD Model

Step 1 QFD preparation (See section 4.3 for details)

Processes in this step follow the normal QFD process. Key items to be obtained:

- Major quality characteristics of product
- Processes critical to product quality
- Processes critical to production efficiency
- Layout of resources for each production system
- Major competitors' status related to product quality and efficiency.

Step 2 Using the identified relationship between the quality and production process as a guideline to identify key processes for quality improvement or production efficiency.

With the information from QFD phase 1, phase 2, and phase 3, relationships between quality / production efficiency and processes could be seen. Combining them with the market status, shown in phase 1, companies could identify investment opportunities. See Fig. 24. The relationships between product quality / efficiency and processes could be one-to-one, one-to-many, or many-to-many.

Step 3 Using the results from step 2 as a guideline to screen investment opportunities.

Companies could use the results from step 2 as guideline to screen investment opportunities. For example, a company may want to study whether a new type through-hole-drilling machine is worth the investment or not. The company could start the study with QFD phase 3 data. First, the company needs to determine whether the through-hole drilling process is one of the critical quality-related processes. If the answer is yes, then further study will follow. A company could also use the QFD data to trace the process of new machine back to the defined qualities. Based on the priority level, the company could decide whether to conduct a further study. See Fig. 25.

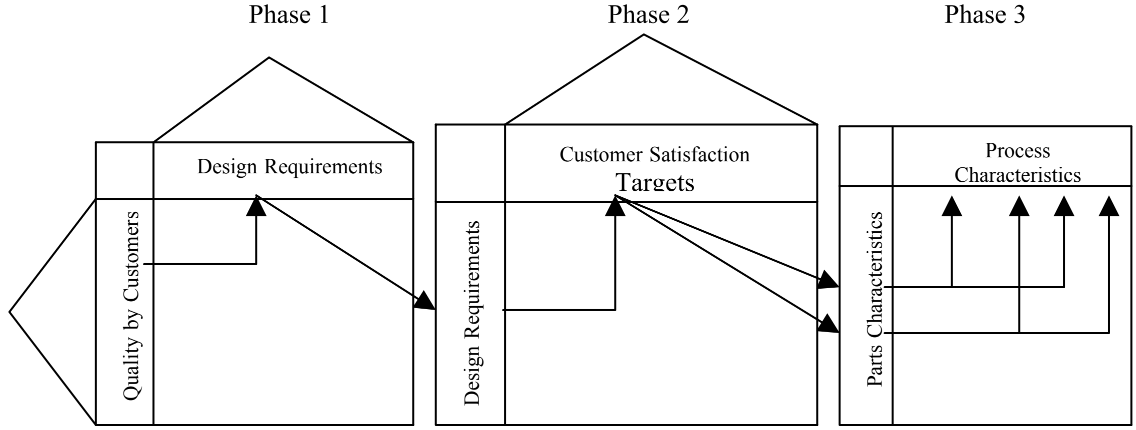


Fig. 24 – Relating the Product Quality to Production Process

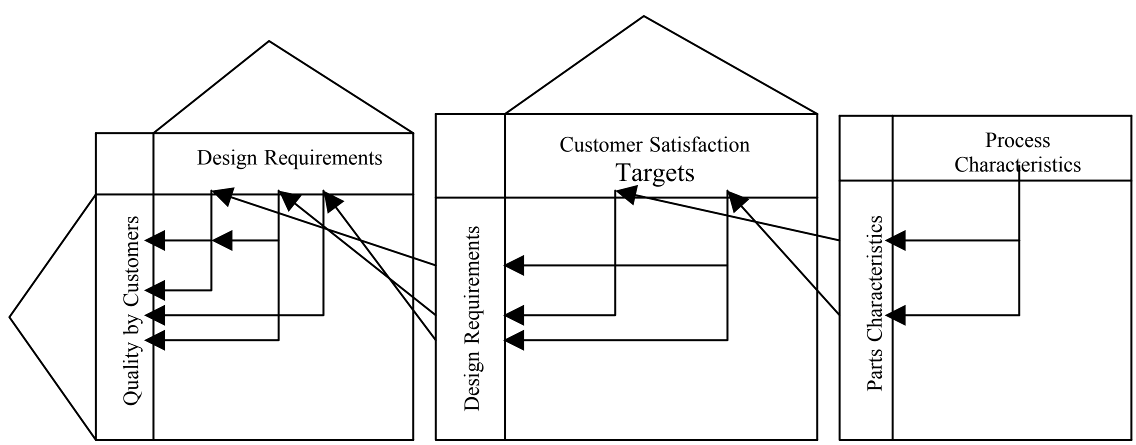


Fig. 25 – Tracing the Processes Back to Product Qualities

Step 4 Deploying the screened candidates from step 3 into detail-production processes.

After step 2, a production-process deployment will follow. The process deployment is not only to realize how the screened candidates could improve product qualities / efficiency, but also to study how they impact product cost. QFD phase 4 will be adapted to deploy the production processes. After the production-process deployment, the process-related resources would be shown. The resource data, such as power consumption, could be obtained from the vendor, or estimated by experienced line manager for example, labor.

Step 5 Combining the costs and the results from step 4 to see how cost-effective the investment will be.

In step 5, the production process will be deployed into activities. Combined with cost information, the related production cost can be obtained. Then, the cost impact of the investment candidates on products could be studied. See Fig. 26:

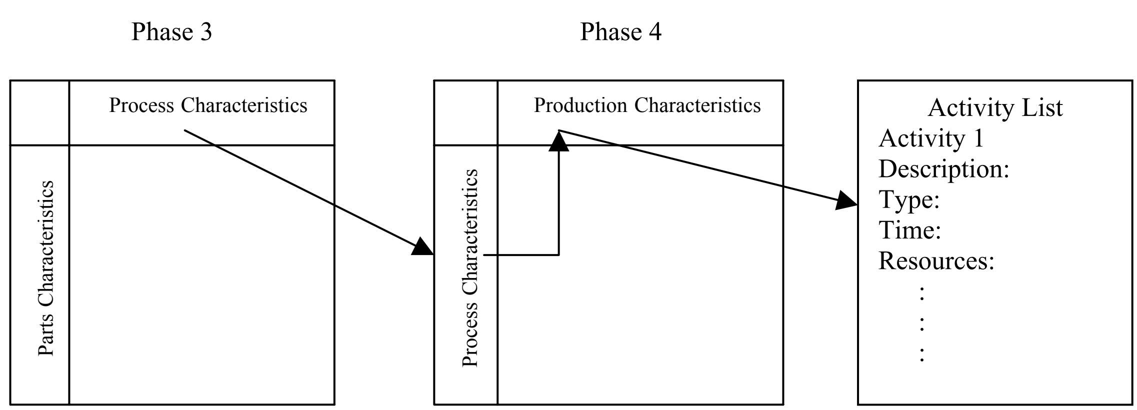


Fig. 26 – Flow Chart of Deploying the Process into Activities

To make a final decision on the investment, an overall economics study is necessary. In today's commercial environment, cost is not the only factor that impacts competition power. Quality is also a major market factor. Because of the global-warming effect, environmental factors become more and more important to products. As a result, to evaluate an investment opportunity a company should include the quality and environmental cost.

Model Description

Information Collection and Analysis

The information collection and analysis process is a critical process for companies. The information to be collected includes new technologies, market, and operation etc. Then they will be analyzed for whether and how they will impact the company. As in the General Model:

- New technology Information

Companies should always keep an eye out for new technologies. With QFD data, company could focus more on quality-related new technology.

- Market Information

As in the General Model.

- Operation Information

With QFD phase 3 data, a company could find out what in the production process that is highly related to product quality can be or needs to be improved.

- Impact Study

Once the relevant information is collected, a study of how they will impact a company or even the whole industry is necessary. The result of this process will be used in the later processes.

High-Level Investment Opportunity Screening

With input from the impact study and data supplied in QFD phase-3, economic and non-economic study will follow, as in the General Model.

Deciding Objectives to Be Achieved

Once past the High-Level Investment Opportunity Screening process, a set of objectives to be achieved in this investment project will be generated. These objectives could be market, production, or strategy objectives etc. These objectives could be requirements from customers too. All these objectives should be consistent with company's long-term or short-term objectives. At the end of this process, these objectives will be ordered by priority, as described in the General Model.

Generation of Alternative Implementation Plans

Based on the qualified action plans generated by previous processes, alternative implementation plans that could achieve these action plans will be generated. The implementations plans are high-level plans such as outsourcing the action.

Selection of Optimum Alternative

Once alternatives are generated, the one that can most maximize project objectives is selected.

Auditing / Controlling / Measurement System Building

Once the action plans and implementation plans are chosen, a measurement system should be built to monitor progress.

Approval & Execution

After the best one is selected, it has to be approved by related parties in the company, and then executed.

4.2.3 Proposed ABC Model

Fig. 27 shows a process flow chart of the ABC model.

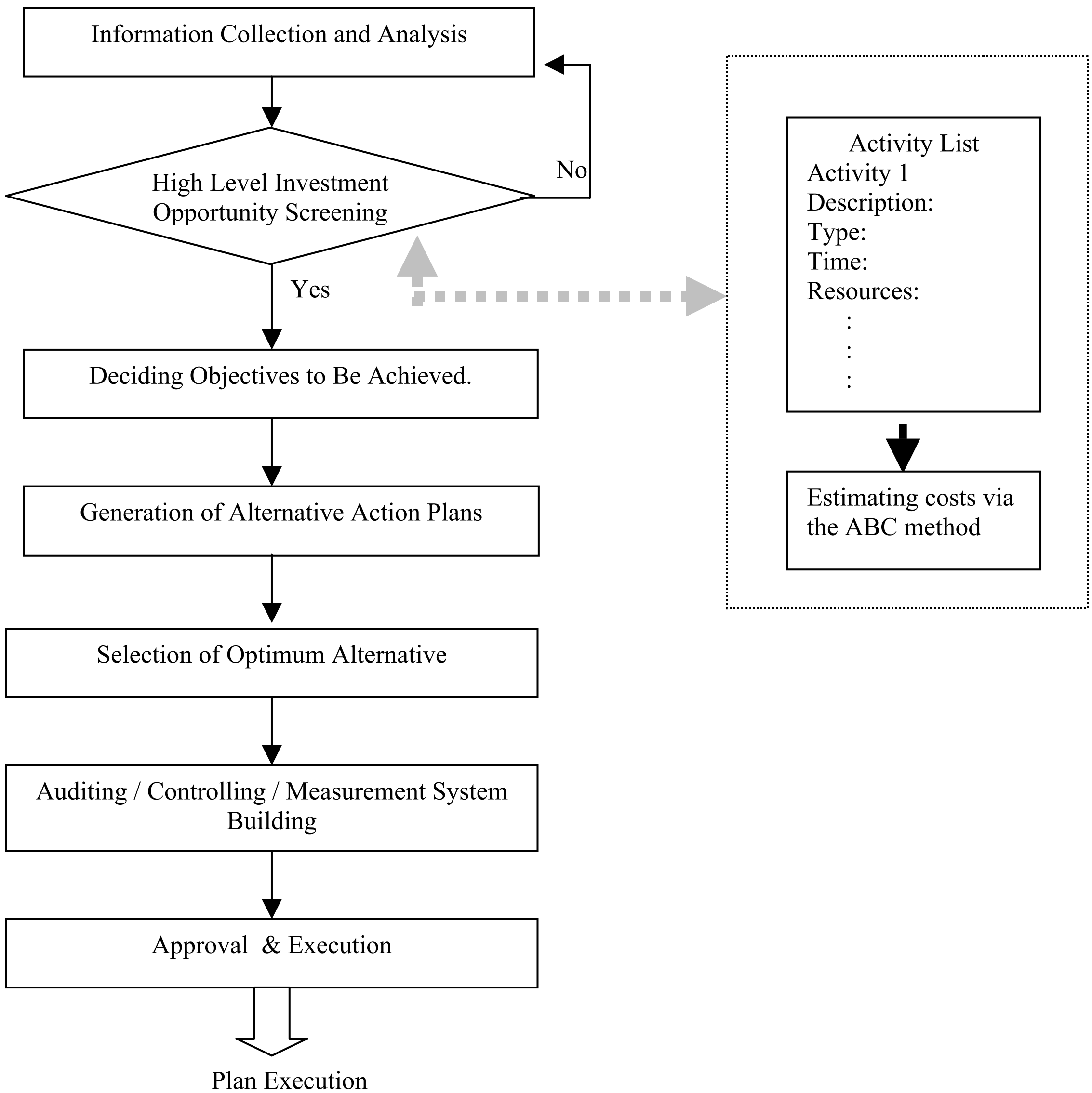


Fig. 27 – Flow Chart of the ABC Model

Model description

In the ABC model, most sub-processes are the same as in the General model except, the “High-Level Investment Opportunity Screening” sub-process. In the “High-Level Investment Opportunity Screening“ sub-process in the ABC model, cost information from ABC is added into the evaluation process.

Information Collection and Analysis

The information collection and analysis process is a critical for companies. The information to be collected includes new technologies, market, and operation. Then, they will be analyzed for whether and how they will impact the company.

- New Technology Information

Companies should always keep an eye out for new technologies all the time. New technologies could change a company’s operation flow and product lines. New technologies could also bring revolutions to industries.

- Market Information

Market information about the percentage of the whole market company has and how much a company wants to increase in the future is one of the major driving forces that trigger the company’s investment activities. The new market is also one of the major driving forces. A company could invest either in new technologies or in existing technologies to increase production. Investments that are driven by the market are very critical to industries with a short product lifecycle.

- Operation Information

Operational needs are driving forces for investments too. To increase production capacity or product quality is a major trigger of these operation needs. Recently, investing in Information Technology (IT) to help companies to gain competitive power has become a hot issue in every industry. Computer systems like Enterprise Resource Planning (ERP), Supply Chain Management (SCM), and Customer Relationship Management (CRM) help companies to increase their quality of operations.

- Impact Study

Once the related information collected, a study on how they will impact your company or even the whole industry is necessary. The result of this process will be used in the later processes.

High-Level Investment Opportunity Screening

This process is also critical. The quality of the results of the Impact Study and this process will impact the future of a company. With input from the Impact Study, economic and non-economic studies will follow. In this process, a decision of whether or not to invest will be made. A list of how the collected information will impact the company will be made based on the result from the Impact Study process. A list of how the company could respond to these impacts will be generated. With these two lists, economic and strategy benefits will be studied. A “pass” or “fail” decision will be reached based on the results of studies.

Deciding Objectives to Be Achieved

Once past the High-Level Investment Opportunity Screening process, a set of objectives to be achieved in this investment project will be generated. These objectives could be market, production, or strategy objectives. These objectives could be requirements from customers too. All these objectives should be consistent with company’s long-term or short-term objectives. At the end of this process, these objectives will be prioritized.

Generation of Alternative Action Plans

Based on the qualified objectives list generated from previous processes, alternative plans that could achieve these objectives will be generated.

Selection of Optimum Alternative

Once alternatives are generated, the one that can most maximize project objectives is selected. In this model, cost data generated with ABC should be considered.

Auditing / Controlling / Measurement System Building

Once the action plans and implementation plans were chosen, a measurement system should be built to monitor the progress.

Approval & Execution

After the best alternative is selected, it has to be approved by relevant parties in the company, and then executed.

4.3.4 Proposed Integrated Model -Model with QFD and ABC

"Low efficacy and high costs due to poor quality at process level are consequences of two main factors: First, not enough understanding of customer's concept of value; second, noise during communication throughout the organization" [Carlos Augusto De Oliveira and Andre Luiz Melo Da Cunha, 1997; Ref. 117]. For the PCB fabrication industry, processes are highly automated. The quality and cost of products are pre-decided to certain level when the decision about which facilities to invest in is made. The decision about which manufacturing facilities to invest in will impact a company's competitiveness.

In section 4.2.1, we had discussed the general decision-process model. If we focus on the investment-decision process in the production phase, what decision process model will it be? What analysis techniques could be used in decision analysis? How should the decision process flow in Fig. 19 be modified to fit into the production phase? When and how will QFD and ABC be used in the decision-making process? As the major purpose of this dissertation, the author will study how QFD and ABC impact investment decisions in the PCB fabrication industry. See Fig. 28 for flow chart of this model.

Information Collection and Analysis

When focusing on the manufacturing phase, the information to be collected, includes new technologies/market/operation, mainly focuses on how it impacts production. How will new technologies improve product quality or production efficiency? Does the company need to set up another production line to meet the market needs, or for new product? Do any current operations need to be improved, in quality or efficiency? See Fig. 20 for a process flow chart.

- New Technology Information

In the manufacturing phase, evaluation of new technology will focus how it will improve overall production quality and efficiency. Sometimes, new technologies change some processes either in quality or efficiency. Sometimes, new technologies change all processes. How new technology information will be put into QFD process in decision making will be described in later paragraphs.

- Market Information

For a PCB fabrication company, market information about how much market demand there will be in the near future, what new product features there will be, or what the predicted price for every product will be are major concerns.

- Operation Information

Information about time, cost, and resource usage is to be collected all the time. Most importantly, the relationship between production process and product quality & efficiency should be worked out and recorded all the time. Also to be studied are the production activities. In each production process, how much individual activity is involved? How much labor and time are required for each activity?

- Impact Study

The impact study in the production phase should focus on what competitive position a company is in now and what the statuses of major competitors are.

High Level Investment Opportunity Screening

PCB fabrication is a highly automated industry. Investment-opportunity screening can focus on how much production efficiency or product quality can be improved. In later paragraphs, how ABC could help companies to make decisions in the process will be studied. See Fig. 21 for a process flow chart.

Since the PCB-fabrication industry is highly automated, the process costs will be easier seen with ABC method. Once a decision on which machine one wants to invest in is decided, a certain portion of the process costs is pre-decided. The process cost information via the ABC study will be very helpful in decision-making.

Deciding Objectives to Be Achieved

When an investment opportunity is identified, a set of objectives of quality, production efficiency, and/or market share to be achieved will be decided and used later on in detail evaluation and investment monitoring. See Fig. 22 for a process flow chart. The objectives could be set in the QFD process. The process for it will be described in later paragraphs in this dissertation.

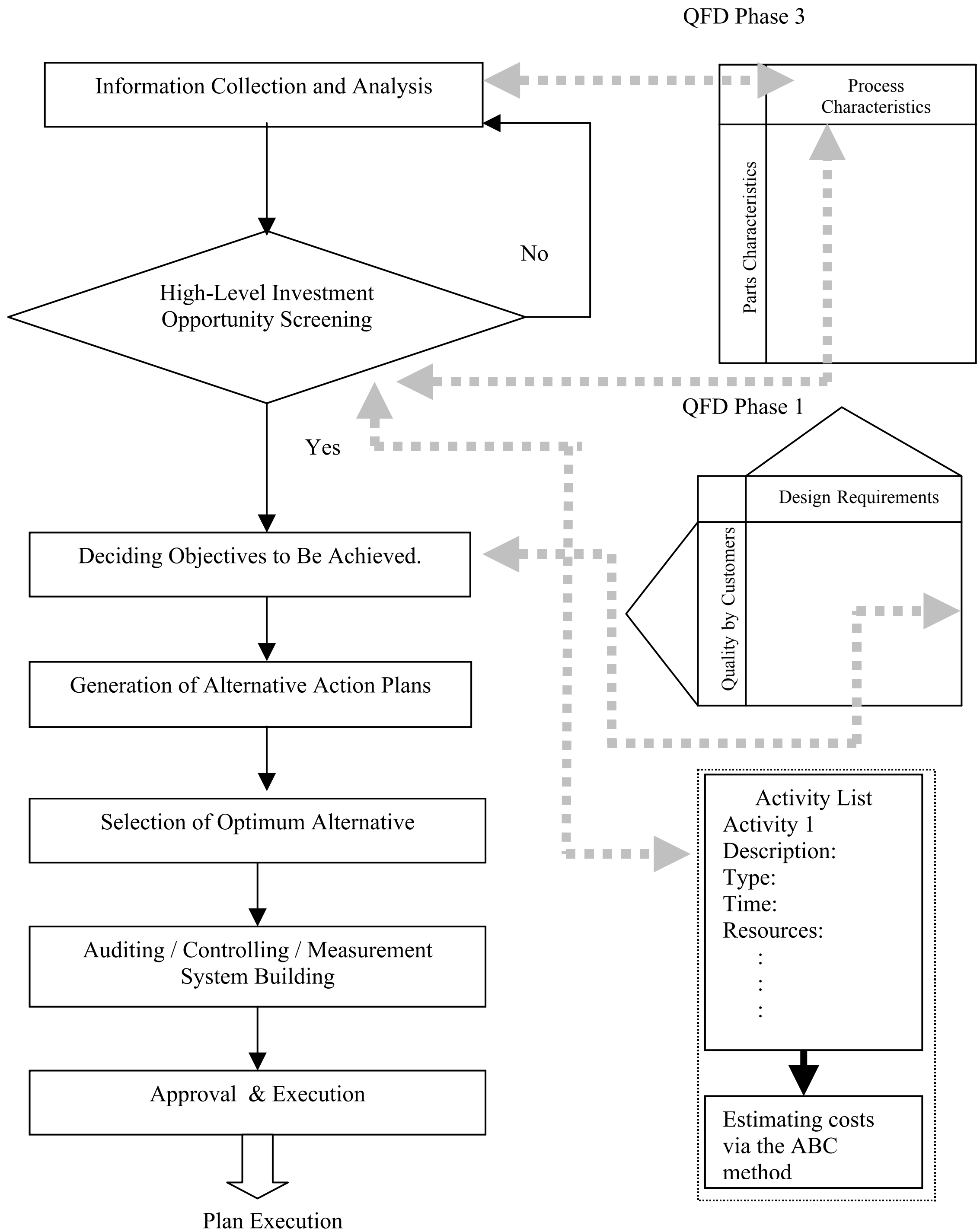


Fig. 28 – Flow Chart of the Integrated Model

Generation of Alternative Action Plans

Based on the generated qualified objectives list from the previous process, alternative plans that could achieve these objectives will be generated.

Selection of Optimum Alternative

Once alternatives are generated, the one that can most maximize project objectives is selected. In this model, cost data generated via ABC method should be considered.

Auditing / Controlling / Measurement System Building

Once the best action plan is chosen, a measurement system should be built to monitor progress.

Approval & Execution

After the best one is selected, it has to be approved by relevant parties in the company, and then executed.

4.3 The QFD Processes Road Map

The QFD process road map, Fig. 29, is based on QFD Designer by Qualsoft. See QFD Designer menu for detailed descriptions of each phase.

Phase 1 Product Planning (House of Quality Chart)

In product planning, a company collects information about how its customers define the quality of its product, and then relates the collected information to design requirements. The major purpose of this phase is to capture the "voice of customer" and translate it into design requirements, or the company's internal design terms. By doing this, decision makers can know what to focus on in a project.

Phase 2 Design Planning

In this phase, the target values of all design requirements are to be set. The major purpose of this phase is to establish the optimum materials and design.

Phase 3 Process Planning

The major purpose of this phase is to find the optimum process to meet the design target values determined in phase 2.

Phase 4 Production Planning

The purpose of this phase is to work out what implementation parameters need to be addressed to insure the success of the optimized process in phase 3.

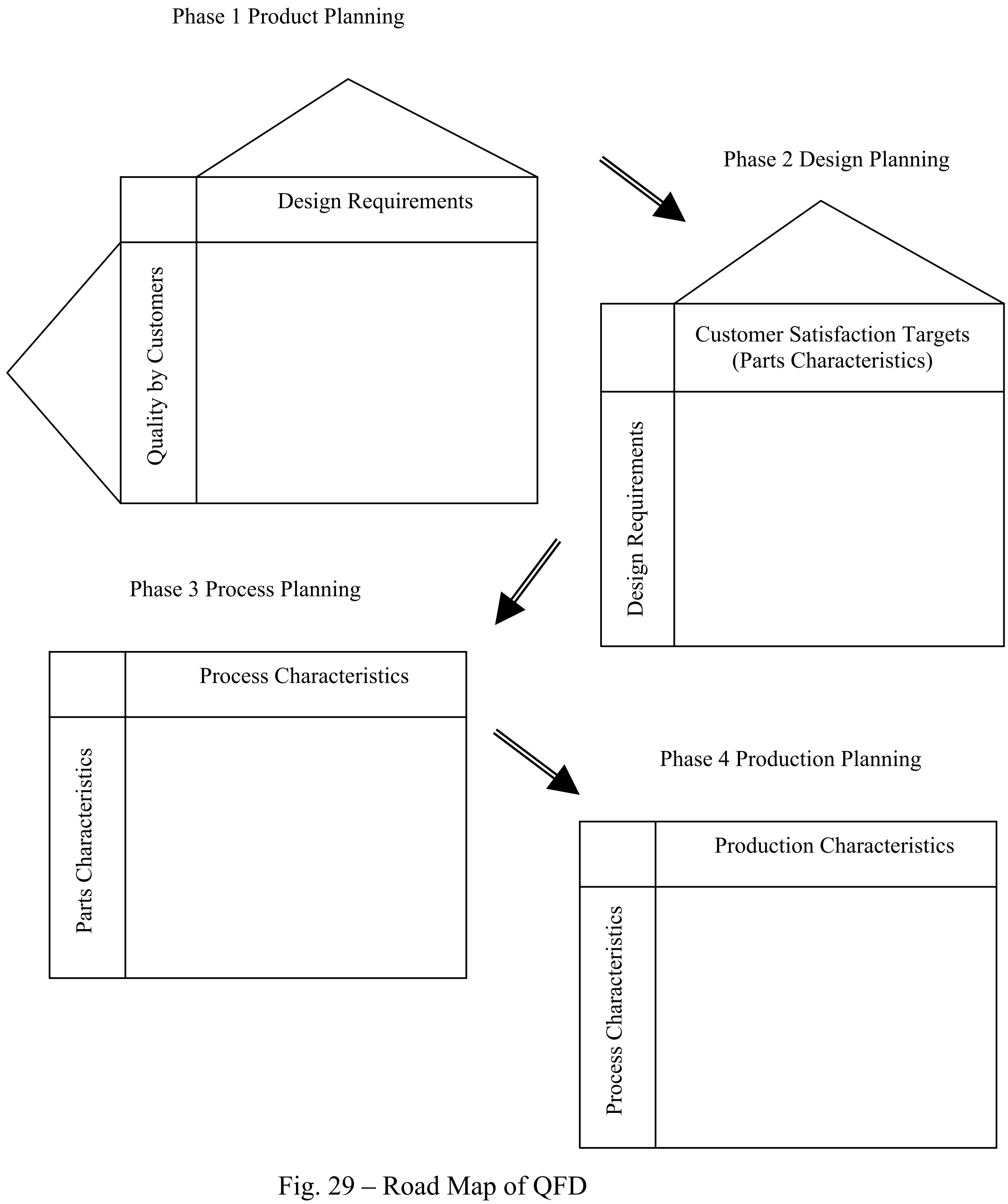


Fig. 29 – Road Map of QFD

4.4 Three Application Indexes

In this dissertation, the author has defined three indices that help decision-makers make decisions in different cases. These three indices are the Superior Index (SI), Customer Satisfaction Index (CSI), and Confidence Index (CI). They are based on the data in the House of Quality. The author assumes that the processes that are broken down from customers' requirements are known and studied. The definitions are as follows:

Superior Index (SI)

To be used in a venture capital case, for a specific product or market, with alternative proposals to choose from.

$SI = \Sigma$ (Relative importance of EC_i) * (U_i)

SI: Superiority Index

U: Utility value of EC_i: 1-10

where

Relative importance = (Importance of individual EC) / Σ (Importance of individual EC)

V (market) ≡ Θ (CV)

where

V: Market share or Revenue

CV: customer voice/requirement or market requirement

Θ: Function of market, which relates major CVs to market share

$CVi \equiv \forall(ECi)$

where

EC: Engineering Characteristic or Internal process

∀: Function of customer voice that relates major ECs to CVs

$$\Rightarrow \quad V\,(market) \equiv \Theta\,(CV)$$

$$\equiv \Theta\,(\forall(ECi))$$

$$\equiv \Xi\,(ECi)$$

Ξ: Function of market that relates major ECs to market

- Max value of SI is 1,000.
- The final decision will be based on the Superior Index. Alternative with the highest Superiority Index wins.
- The utility value of EC is based on the evaluation of each alternative's performance of specific EC. Recommended range is 1 – 10.
- The utility value of each EC of the individual company is assigned via utility function, scaling method, or AHP.

The logical relationships of the above variables are explained in following paragraphs. From market practice, the market share of the product is highly related to customer requirements, sometimes called customer voices. The more a product meets customers' requirements, the more market share it will have. Briefly, market share is a function of "how well customers' requirements are met".

"how well customers' requirement are met" is related to production process. When QFD is used in product design, customers' requirements are broken down into Engineering Characteristics (ECs) in the House of Quality. When QFD is used in capital-investment evaluation, customers' requirements are broken down into major internal processes that create the product or service. Simply, "how customers' requirement are met" is a function of related internal processes.

The relative importance is the ratio of "weight of individual EC" over "total weight of all major ECs" in percentage. The relative importance is then multiplied by the utility value assigned by the decision makers. The SI is the summation of the production of utility value of EC and its relative importance. The result means: how much does an alternative scores out of 1000. The alternative that has the highest score wins. See Example 1 in Appendix C.

Customer Satisfaction Index (CSI)

To be used in company market-performance improvement or venture-capital case with one alternative.

$CSI = \Sigma$ (Relative importance of EC_i) * (CR_i)

where

CSI: Customer Satisfaction Index

$CSI \equiv \Pi(CVi)$

where

CSI: Customer Satisfaction Index

CV: customer voice/requirement or market requirement

Π: Function of Customer Satisfaction that relates major CVs to CSI.

$CVi \equiv \forall(ECi)$

where

EC: Engineering Characteristic

$V\ (market) \equiv \Phi\ (CSI)$

where

V: Market share or Revenue

Φ: Function of market that relates CSI to market share.

⇨ $V \equiv \Phi\ (\Pi(CVi))$

⇨ $V \equiv \Phi\ (\Pi(\forall(ECi)))$

⇨ $V \equiv \Gamma(ECi)$

$$V_T\ (market) \equiv \Phi_B\ (CV) \equiv \Phi_B\ (\forall(ECi)) \equiv \Gamma_B\ (ECi)$$

where

Γ_B: Function of market that relates ECs or internal processes to market share

V_T: Market share could be achieved with **target** setting of ECs or internal processes.

Note: The target setting is based on surveys or judgments by study teams.

$$CR_i = (\text{Utility value of target setting of } EC_i - \text{Utility value of min. setting of } EC_i) / (\text{Utility value of best setting of } EC_i - \text{Utility value of min. setting of } EC_i)$$

CR_i: Confidence ratio of EC_i

Note: 1. The best setting of EC is the setting of the market player with the best performance.

2. Min. setting of EC is the setting of the market player with the least performance.

3. The recommended number range for utility value is 1 – 10.

If a CSI is less than that of the current target market player, the proposal should be rejected. If the CSI is greater than that of the current highest market player, the proposal may be accepted.

By identifying the key engineering characteristics, decision makers can map the internal processes into different market strategies by adjusting key internal processes. See Example 2 in Appendix C.

The logical relationship between market and internal processes is as stated in the Superior Index. The market share will differ if the settings for related processes are different. For example, if a company decides to change its customer-service response time from four hours to twenty minutes, and the customer-service response time is one of the critical indices, a service response time of twenty minutes should have more market share than one with four hours.

In CSI, the confidence ratio is defined with facts: in existing market, customers compare products from different vendors, and then purchase the one that they have most confidence in. A “complete” product includes the product itself and the services related to delivering this product. As seen from the formula, the confidence ratio is defined based on the assessment data of the major players. It reflects the dynamics of market.

Preferred Confidence Index (PCI)

To be used in venture-capital cases of different products or markets, with alternative proposals to choose from and their economics and strategy performances roughly equal.

$V\ (market) \equiv \Theta\ (CV)$

$CV_i \equiv \forall(EC_i)$

where

V: Market share or Revenue

CV: customer voice/requirement or market requirement

EC: Engineering Characteristic or related process

Θ : Function of market that relates customer voice to market share.

$$V_M\ (market) \equiv \Theta_B\ (CV) \equiv \Theta_B\ (\forall(EC_i)) \equiv \Xi_B\ (EC_i)$$

where

V_M: Target market share could be achieved with the **minimum** acceptable setting of ECs.

Note: The minimum setting is based on survey or judgment by study team.

$PCI = \Sigma\ (Relative\ importance\ of\ EC_i) * (CN_i) / 10$

where

PCI: Preferred Confidence Index, Best value is 100

CN: Confidence Number. 1-10: “1” means lowest confidence, “10” means highest confidence. Confidence level is the number assigned to each EC based on its setting. If the setting is much better than the minimum setting, the number “10” will be assigned. When the setting is closer to the minimum setting, the lower number should be assigned.

Relative importance = (Importance of individual EC_i*) / Σ (Importance of individual* EC_i*)*

The final decision is based on PCI. The alternative with the highest PCI wins.

The logical relationships between variables in the above formulas are the same as in the Superior Index. The difference is: In Superior Index, decision-makers use the same set of ECs to evaluate different proposals that work on the same product. The result gives decision-makers an idea of which alternative is the best. In the Preferred Confidence Index, decision makers use different sets of ECs to evaluate different proposals that work on different products. The result shows which alternative decision-makers will have most confidence in. See Example 3 in Appendix C.

4.5 Method for Model Validation and Evaluation

The method used to validate and evaluate models is an expert panel. There will be five to seven industry experts on the panel. The author presented and described each model to the experts. See appendix A for the presentation package. In order to make it clearer for interviewees, the author created a demo case showing how the models were implemented. The experts will be asked to fill out the related survey at the end of each model presentation. In the survey, experts will be asked to validate or evaluate the models according to what is claimed in the question. See appendix B – survey questionnaires – for survey questionnaire detail.

Industry experts will be asked whether each model is applicable to the PCB fabrication industry. Then, they will be asked whether they agree with what the author claim in each model in this research. The results of survey will be statistically tested with t-test. Lastly, experts will be asked to compare models.

The survey questionnaires are based on a five points Likert scale. The meaning of the numbers is as follows:

1 - Strongly Disagree

2 - Disagree

3 - Neutral

4 - Agree

5 - Strongly Agree

The author expects that industry experts agree, statistically significant (t-test, $p < 0.05$), what this research claims for each question.

5. Result Analysis

5.1 Results of Literature Review

The results of the literature review will be given in this section. There are two parts in result of literature review: the decision-making and capital-investment evaluation models.

5.1.1 Results of Literature Review of the Decision-Making Models

The result of the literature review of the decision-making models is givend in this section. The decision –making models and the form of technique may be tabulated in Table 2, based on the state of nature: [Clayton Reeser, 1972; Ref. 1]

Table 2: Form of Technique vs. Specific Technique

STATE OF NATURE	FORM OF TECHNIQUE	SPECIFIC TECHNIQUE
Relative certainty	Deterministic	Linear programming Break-even analysis Equipment replacement analysis
Known risk	Objective probabilistic	Queuing theory PERT (CPM) Monte Carlo Simulation
Relative uncertainty	Subjective probabilistic	Decision theory Game theory Bayesian statistics

If based on the solution type, the decision-making tools and their business applications may be tabulated as in Table 3.

Definitions of terms:

Fixed solution: solutions to the problem are available and well studied.

As long as the user can identify what problem is, the solution could be allocated. Conceptually, the major task of problem solving is matching the problem and its optimal solution(s). Expert systems, by nature/cost effectiveness/service efficiency, are suitable for handling problems that happen frequently.

Constrained optimal solution: solutions are constrained by certain natural or artificial conditions, and all conditions can be presented by linear equations.

The major tasks in this kind of problem solving are transforming the conditions into equations and computation.

Objective best-among-available: solution(s) to the problem depend(s) on specific variables, and these variables are not all in the same domain. Some of them may be monetary variables; others may not.

Each variable can be assigned a utility value based on its related utility function or utility graph. Also, assigned to each variable is the “weight”. The final decision is made based on the weighted-utility value. The solution with the highest weighted-utility value is the winner. The major tasks in this kind of decision-making are: 1. Weight-assigning for each variable. This process is to be carried out by key decision makers; 2. Utility-function building or verifying. In this process, historical data is used to build or verify the utility functions. Because the utility values are calculated from utility-functions, the result is “relatively objective”.

Subjective best-among-available: solution(s) to problem depend(s) on the criteria decision-makers choose and the relative value for alternatives regarding each criteria.

For each criterion, decision-makers determine a relative value for each solution alternative. This process is done by pair-wise comparison. The final decision is based on total weighted value. The major tasks in this kind of decision-making are: 1. Weight-assigning for each criterion. This process is to be carried by key decision makers. 2. Value assigning for alternatives relating to each criterion. Value is assigned based on current available information, and decision makers' "subjective" judgments.

Table 3: Model vs. Business Application

SOLUTION TYPE	MODEL TO USE	BUSINESS APPLICATION EXAMPLES
Fixed solutions	Expert System Model	1. Computerized Customer Service 2. Automatic Directory Service 3. Car Diagnosis System 4. Banking System 5. Tax Filling System
Constrained optimal solutions	Linear Programming Based Model	1. Production Planning – Oil Refineries 2. Utility Planning 3. Computer Optimization Tool 4. Finance Advising System
Objective best-among-available	Multi-Attribute Utilities Model	1. Project Evaluation 2. Vendor Selection 3. Capital Allocation
Subjective best-among-available	Analytic hierarchy process (AHP)	1. Project Evaluation 2. Vender Selection 3. Capital Investment 4. Facility Location Selection

5.1.2 Result of Literature Review of Capital Investment Evaluation Models

In today's business environment, markets are dynamic, and the demand from customer is always increasing. Capital investment is an effective way to handle this situation. Because of the dynamic markets and increasing demand, companies are after a "moving target". Capital investment becomes fraught with relative uncertainty. To lower the degree of uncertainty, decision models have been developed to guide decision-makers.

From literature research, we found that a comprehensive capital investment evaluation model should encompass seven activities [G. Gallinger, 1980; Ref. 97] [G. Pinches and L. Gordon, 1984; Ref. 98]:

1. Strategic Analysis
2. Establishing investment goals
3. Searching for investment opportunity
4. Forecasting investment cash flow
5. Risk-adjusted evaluation of forecasted cash flow
6. Decision-making
7. Implementation of accepted opportunities post-audit performance.

See section 2.4.3 for detailed descriptions of each activity.

It is indirectly verified in surveys that U.S. S&P industrial index companies encompassed these seven activities in their capital-evaluation process. These surveys were done by: Klammer in 1969; Gitman/Forrester in 1977 [L. Gitman and J. Forrester, 1977; Ref. 94]; Kim/Farragher in 1979 [S. Kim and E. Farragher, 1981; Ref. 95]; and Klammer/Boch/Wilner in 1988 [T. Klammer, B. Koch, and N. Wilner, 1991; Ref. 96].

Farragher, Kleiman, and Sahu tabulated the results of these surveys in different time periods in 1999. See section 2.4.2 for detail.

The General Model in this research is built based mainly on the above research results. The review of models built by other researchers also helps in building the General Model. The comparison between major models referenced in this research is in Table 4. The comparison is based on the overall comprehensiveness of the decision-making process. The comprehensiveness is based the "seven activities".

Table 4: Model Comparison Based on Seven Activities

	A	**B**	**C**
Strategy Analysis	*	X	X
Searching for investment opportunity	X	X	
Establishing investment goals		X	X
Forecasting investment cash flow	X		X
Risk-adjusted evaluation of forecasted cash flow	X		
Decision making	X	X	X
Implementation of accepted opportunities			

A: AMT investment decision model, By Kumar, Murphy, and Loo

B: **Integrated model with Expert System approach,** By Cil and Evren, 1998

C: **Investment Justification Model using ABC and AHP**, By Jiang and Wicks, 1998

Note: See related paper for model details.

5.1.3 Summary of Literature Review

Table 5 lists related authors' contribution. These authors' researches help the author of this research gain insight into capital-investment evaluation models.

Table 5: Other Authors' Contribution

Author(s)	Major contribution
Reeser, 1972	"Quantitative analysis is scientific way to approach decision making. The essence of quantitative analysis is rationality, or the assumption that decision maker, armed with perfect information concerning the outcomes of various alternatives, will logically and without bias choose that one alternative that will maximize the use of his resources."
Pinches, 1982	"focus on the simple selection phase is myopic, and a more global approach is necessary to fully understand the capital budgeting process."
Hodder, 1986	For evaluation of manufacturing investment, "the important issue is how particular techniques are employed with the recognition that output quality depends on input quality. It appears the main focus of our concern should be better procedures for identifying and analyzing critical input assumption rather than whether to regress to less sophisticated processing techniques."
O'brien/Smith, 1993	"decision on investment should be taken on both an analysis of their probable effects on costs and revenues, where known, and on an informed expert assessment of the extent to which the investment will support the strategic objectives of the company."
Small/Chen, 1995	"Meaningful justification also requires the identification and assessment of the variables that determine the success of the AMT project. A key issue in the auditing of AMT projects is determining the critical variables that should be used to measure the performance of the system.

Table 5: Other Authors' Contribution _ cont.

Author(s)	Major contribution
Pandya/Satyre, 1996	Identified factors that affect decision making in the implementation of manufacturing technology. See attachment for detail.
Kumar / Murphy / Loo, 1996	Developing an investment decision model for analyzing AMT investment that formally installs opportunity searching process and links manufacturing and market to investment decision-making process.
Jiang / Wicks, 1997	"The use of ABC to trace the product cost not only provides management with insight into company's operations, but can also provide more accurate and reliable cost data for investment."
Farragher / Kleiman / Sahu, 1999	"While rigorous evaluation an risk analysis tools are important components of a sophisticated capital investment process, investment success depends on improving the entire process, not just on applying rigorous evaluation techniques."
Brisom / Antos, 1999	"feature costing is built on a process-management model. Process management develops an understanding of the process and the factors that cause the process to vary." Product features are an important basis for communicating for sales and marketing, research and development, product engineering, and manufacturing."

5.2 Result Analysis of Survey of Experts

5.2.1 Survey Result and Analysis – Personal data

This section contains data gathered from interview of the expert panel. In total, 10 industry experts within six companies were interviewed. The minimum qualification to be in the expert panel is that an individual should have experience in investment evaluation, no matter what size the investment. The personal information of these experts is tabulated in Table 6.

There is the special case of one member, expert B. Expert B has never worked in the PCB fabrication industry, but he has dealt with PCB-fabrication companies for years.

The panel members' year of experiences in the PCB fabrication industry range from two to sixteen years. The average number of year in the PCB fabrication industry of panel members is:

$$(13 + 16 + 7 + 12 + 10 + 14 + 10 + 6 + 2) / 9 = 10 \quad \text{years}$$

Based on job ranking in companies, the number of members with a high-rank is five, and, with mid-rank, is 5.

Definitions of terms:

High-rank executives in companies: assistant VP and above.

Mid-rank executive in companies: Section manager to Manager.

The investment evaluation is not a routine job. The members of panel are not asked how many year of experience in investment evaluation they have.

Table 6: Personal Information of Experts Interviewed

Member ID	Position in Company	Years in Current Position	Years in PCB-Fabrication Industry
A	Chair & CEO	13	13
B	CEO	2	N/A*
C	CFO	16	16
D	CFO	7	7
E	Associate VP	4.5	12
F	Div. Manager - QRA	0.6	10
G	Assistant Manager - R&D	4.5	14
H	Senior Manager - Sales & Marketing	8	10
I	Section Manager - Sales & Marketing	6	6
J	Specialist -Customer Service	2	2

* This member has never worked in the PCB fabrication industry, has dealt with PCB-fabrication companies for years.

Self-evaluation about specific knowledge of panel member is tabulated in Table 7. The self-evaluation is based on a five point scale: 1 – low, 3 – mid, 5 – high.

I – general knowledge of PCB industry

II – knowledge of capital investment decision-making process in the PCB industry

III - knowledge of Quality Function Deployment

IV - knowledge of Activity Based Costing

Table 7: Member's Self-Evaluation about Specific Knowledge

Member ID	I	II	III	IV
A	5	5	3	3
B	3	3	2	1
C	3	4	4	2
D	4	4	2	1
E	4	3	3	3
F	4	3	3	4
G	4	3	2	2
H	4	3	1	3
I	4	4	3	2
J	4	3	3	3
Average	3.9	3.5	2.6	2.4

5.2.2 Survey Result and Analysis – Models

In this research, members of the panel were asked to evaluate the models using a 1 – 5 scale.

1: Strongly Disagree. 2: Disagree. 3: Neutral. 4: Agree. 5: Strongly Agree

The statistical analysis process for survey data analysis is as follows:

1. calculate mean; 2. calculate standard deviation; 3. calculate Standard error; 4. statistically t-test on hypothesis at 95% of confidence level

For t-test of this research, the alternative hypothesis is "industry experts agree on what the author claims in the survey questionnaires." If the sample mean of a surveyed question's result is statistically significantly greater than "3" (Neutral), then we may conclude that the population mean is greater or equal to "4" (Agree or Strongly Agree). Therefore, the hypotheses are:

H_0: $\mu = 3$

H_1: $\mu > 3$

The critical value, $t_{0.05}(9)$, 95% confidence level with 9 degree of freedom, of right-tailed t-test is 1.833 [David C. Howell, 1999; Ref. 118]. If the calculated t value is greater than $t_{0.05}(9)$, we conclude that industry experts agree on what is claimed in questionnaire.

For the QFD and ABC Models, a Reliability analysis will be taken on related questionnaires to assess the internal consistency of new indices. See detail in the analysis of each model.

5.2.2.1 The General Model

The survey questionnaires of General Model are as follow, and the analysis result with raw data is tabulated in Table 8.

I. "General Model covers major steps in capital investment decision-making processes"

II. "General Model is applicable to PCB industry practice"

Table 8: Data Summary of Survey of the General Model

Member ID	I	II
A	3	3
B	3	4
C	5	4
D	4	5
E	4	4
F	5	4
G	4	4
H	4	4
I	4	4
J	4	4
Statistics of result analysis		
Mean	4.00	4.00
Std. Deviation	0.67	0.47
Std. Error Mean	0.21	0.15
Calculated t value	4.743	6.708

Summary of the General Model

The result of analysis of General Model is summarized in table 9.

Table 9: Summary of Result Analysis of the General Model

Description of Alternative Hypothesis	Mean Score	Greater than 3 at 95% significance
1. General Model covers major steps in capital investment decision-making processes	4.00	Yes
2. General Model is applicable to PCB industry practice	4.00	Yes

As a result, the General Model could be a reference model for capital investment evaluation model in PCB fabrication industry. And it could be a base model for model benchmarking.

5.2.2.2 The QFD Model

The survey questionnaires of the QFD Model are as follow, and the analysis result with raw data is tabulated in Table 10.

I. "Model with QFD is applicable to the PCB industry"

II. "Model with QFD helps decision-makers focus on meeting customer requirements"

III. "Model with QFD helps in identifying the key processes required to meet customers' requirements"

IV. "Model with QFD provides a good communication platform for decision-makers"

V. "Model with QFD provides decision makers good data quality for decision-making"

VI. "Model with QFD helps decision-makers identify key decision-making attributes"

VII. "Overall, Model with QFD is better than the General Model"

In today's business, how to meet the customers' requirements is a hot topic. It is straightforward, a good capital-investment evaluation model should be able to provide what are claimed in survey questions I to VI. In this research, the author also studied "overall, how industry experts feel about QFD Model." The new variable, Z - "The QFD Model is a good capital investment evaluation model", is created for this purpose. The new variable, Z, uses score mean of questions I to VI. A Reliability analysis, Alpha model, will be performed to assess the internal consistency. The Reliability analysis of this new variable is tabulated in Table 11.

Table 10: Data Summary of Survey of the QFD Model

Member ID	I	II	III	IV	V	VI	VII	Z
A	4	4	4	4	4	4	4	4.00
B	4	5	5	5	5	5	5	4.83
C	4	4	4	5	4	4	5	4.17
D	5	5	5	4	5	5	4	4.83
E	4	5	5	5	5	5	5	4.83
F	4	5	4	4	4	4	4	4.17
G	4	3	3	4	4	4	3	3.67
H	4	4	5	4	4	5	4	4.33
I	5	4	5	3	4	5	5	4.33
J	4	4	4	5	4	5	4	4.33
Statistics of result analysis								
Mean	4.20	4.30	4.40	4.30	4.30	4.60	4.30	4.35
Std. Deviation	0.42	0.67	0.70	0.67	0.48	0.52	0.67	0.39
Std. Error Mean	0.13	0.21	0.22	0.21	0.15	0.16	0.21	0.12
Calculated t value	9.000	6.091	6.332	6.091	8.510	9.798	6.091	10.989

Table 11: Statistics for Scale of Variable X in the QFD Model

Mean	Variance	Std. Dev.	N of Variables
26.1000	5.4333	2.3310	6

Reliability Coefficients 6 items

Alpha = 0 .7411 ***Standardized item alpha = 0 .7474***

An acceptable level of internal consistency would be reflected in an alpha value of no less than 0.7 [Chava Frankfort-Nachmias and David Nachmias , 2000; Ref. 119]. The result of reliability test of variable Z in the QFD Model is 0.7411 > 0.7. The author concludes that the variable Z in QFD Model is reliable for profiling a good capital investment evaluation model.

Summary of the QFD Model

The analysis result of QFD Model is summarized in Table 12.

Based on the statistical test, we conclude that:

1. The QFD model is an applicable good capital-investment evaluation model for PCB fabrication industry.
2. The QFD model is a better model than the General Model.

Table 12: Summary of Result Analysis of the QFD Model

Description of Alternative Hypothesis	Mean Score	Greater than 3 at 95% significance
1. Model with QFD is applicable to PCB industry	4.20	Yes
2. Model with QFD helps decision makers focus on meeting customer requirements	4.30	Yes
3. Model with QFD helps in identifying the key processes required to meet customers' requirements	4.40	Yes
4. Model with QFD provides good communication platform for decision makers	4.30	Yes

Table 12: Summary of Result Analysis of the QFD Model _ cont.

Description of Alternative Hypothesis	Mean Score	Greater than 3 at 95% significance
5. Model with QFD provides decision makers good data quality for decision-making	4.30	Yes
6. Model with QFD helps decision makers to identify key decision-making attributes	4.60	Yes
7. Overall, Model with QFD is better than General Model	4.30	Yes
8. QFD Model is a good capital investment evaluation model	4.35	Yes

5.2.2.3 The ABC Model

The survey questionnaires of the ABC Model are as follow, and the analysis result with raw data is tabulated in Table 13.

I. "Model with ABC is applicable to the PCB industry"

II. "Model with ABC enhances decision-makers' understanding of the cost structure of a company's future services"

III. "Model with ABC enhances the quality of cost data used in decision making processes"

IV. "Model with ABC provides good cost information about a company's future services"

V. "Model with ABC provides better decision-making data in decision-making processes than the General Model"

VI. "Overall, Model with ABC is better than the General Model"

In the ABC Model, the author also studied "overall, how industry experts feel about the ABC Model." A new variable, Z - "ABC Model is a good capital investment evaluation model in view of cost information of product", is created for this purpose. The new variable, Z, uses score mean of questions I to V. A Reliability analysis, Alpha model, will be performed to assess the internal consistency. The Reliability analysis of this new variable is tabulated in Table 14. The reliability test result of variable Z of ABC Model in this research is 0.7043 > 0.7. The author concludes that the variable Z in ABC Model is reliable for profiling a good capital investment evaluation model in view of product cost information.

Table 13: Data Summary of Survey of the ABC Model

Member ID	I	II	III	IV	V	VI	Z
A	4	4	4	4	4	4	4.00
B	5	5	5	5	3	5	4.60
C	5	4	4	4	5	5	4.60
D	4	5	5	5	5	4	4.80
E	3	4	4	4	4	4	3.80
F	4	4	4	4	4	5	4.00
G	3	4	4	3	3	3	3.40
H	4	4	4	4	4	4	4.00
I	5	4	3	4	5	5	4.20
J	4	4	3	4	3	4	3.60
Statistics of result analysis							
Mean	4.10	4.20	4.10	4.10	4.00	4.30	4.02
Std. Deviation	0.74	0.42	0.74	0.57	0.82	0.67	0.43
Std. Error Mean	0.23	0.13	0.23	0.18	0.26	0.21	0.13
Calculated t value	4.714	9.000	4.714	6.128	3.873	6.000	6.091

Table 14: Statistics for Scale of Variable Z in the ABC Model

Mean	Variance	Std. Dev.	N of Variables
20.5000	5.1667	2.2730	5

Reliability Coefficients 5 items

Alpha = 0 .7043 Standardized item alpha = 0 .7499

Table 15: Summary of Result Analysis of the ABC Model

Description of Alternative Hypothesis	Mean Score	Greater than 3 at 95% significance
1. Model with ABC is applicable to the PCB industry	4.10	Yes
2. Model with ABC enhances decision makers' understanding of the cost structure of company's future services	4.20	Yes
3. Model with ABC enhances the quality of cost data used in decision processes	4.10	Yes
4. Model with ABC provides good cost information of company's future services	4.10	Yes
5. Model with ABC provides better decision-making data in decision processes than the General Model	4.00	Yes
6. Overall, Model with ABC is better than the General Model	4.30	Yes
7. ABC Model is a good capital investment evaluation model in view of product cost information	4.02	Yes

Summary of the ABC Model

The analysis result of QFD Model is summarized in Table 15. Based on the statistical test, the author concludes that:

1. The ABC model is a good model for PCB-fabrication industry, in view of product cost information.
2. The ABC model is a better model than the General Model.

5.2.2.4 The Integrated Model

The survey questionnaires of Integrated Model are as follow and the analysis result with raw data is tabulated in Table 16.

I. “The Model with QFD and ABC is applicable to PCB industry”

II. “Overall, the Model with QFD and ABC is better than the General Model”

III. “ The Model with QFD and ABC has the synergy effect of Model with QFD and Model with ABC”

Table 16: Data Summary of Survey of the Integrated Model

Member ID	I	II	III
A	4	4	4
B	5	5	5
C	5	5	5
D	4	5	5
E	4	4	5
F	4	5	5
G	4	4	4
H	4	4	4
I	4	4	4
J	4	4	4
Statistics of result analysis			
Mean	4.20	4.40	4.50
Std. Deviation	0.42	0.52	0.53
Std. Error Mean	0.13	0.16	0.17
Calculated t value	9.000	8.573	9.000

Summary of the Integrated Model

The analysis result of the QFD Model is summarized in Table 17. Based on the statistical test, the author concludes that:

1. The Integrated Model is applicable to the PCB industry.
2. The Integrated model is a better model than the General Model
3. The Integrated Model has the synergy effect of the QFD Model and the ABC Model

Table 17: Summary of Result Analysis of the Integrated Model

Description of Alternative Hypothesis	Mean Score	Greater than 3 at 95% significance
1. The Integrated Model is applicable to the PCB industry	4.20	Yes
2. The Integrated model is a better model than the General Model	4.40	Yes
3. Integrated Model has synergy effect of QFD Model and ABC Model	4.50	Yes

6. Discussion

Capital investment has been a hot topic in the past few decades. In today's fast-changing business environment, decision-making in capital investment is like chasing after a moving target. The attributes used by decision-makers for evaluation can changes at any time. Although decision-making is still a major process in a capital-investment evaluation model, capital-investment evaluation model should not focus only on decision-making process [G. Pinches, 1982; Ref. 10]. A capital investment evaluation should be an overall process starting with a search for investment opportunities and ending with implementation of accepted opportunities Post-audit performance. [G. Gallinger, 1980; Ref. 97]

In this research, the author implements QFD and ABC in capital-investment evaluation models. The impact of QFD and ABC on capital-investment evaluation will be discussed in the following paragraphs:

6.1 The Impact of QFD on Investment Evaluation

Being customer-oriented is hotter and hotter in today's business. QFD had been implemented in the back-end stage of business, product design, with great success. QFD helps the design engineer focus on meeting customers' requirements. It also encourages group decision. When implemented in the front-end stage, investment evaluation, what are the benefit to decision makers? To enhance the QFD application, the author defines three indices – the Superior Index, Customer Satisfaction Index, and Preferred Confidence Index. They are to be used in different cases. See Section 4.4 for details.

When QFD implemented in the investment-evaluation process, it provides a structured and systematic approach for decision-makers. From the analysis of the results of interviews with members of the expert panel, QFD also helps decision-makers via or with the following in the capital evaluation stage:

1. Focusing on meeting customer requirements;
2. Identifying the key processes required to meet customers' requirements;
3. Providing a good communication platform for decision makers;
4. Providing decision-makers with good data quality for decision-making; and
5. Identifying key decision-making attributes.

Combined with the related index defined in this dissertation, implementing QFD in the investment-evaluation process could increase decision makers' confidence in their decisions.

Use of the related internal processes as an evaluation reference is encouraged in this dissertation. As from practice with QFD, the customers' requirements could be broken down into internal processes. How satisfied customers are with the product is a measurement index of a company's market performance. It is a result of business operations. The related internal processes are owned and controlled by the company. The company could improve its market performance by adjusting its internal processes. QFD could help decision-makers identify the relationship between the internal processes and market performance. Implementing QFD in the investment evaluation is surely a plus.

6.2 The Impact of ABC on Investment Evaluation

For current production practice, the superiority of ABC systems over traditional costing systems had been discussed in many research papers. Does the superiority of ABC systems over traditional costing systems hold in the investment-evaluation stage? Here, the author means the method of allocating indirect costs.

Although the ABC method is more complex and time-consuming in its process than traditional costing methods, more and more company are adopting ABC for the following reasons:

1. Fierce competition in business causes the shrinkage in profit margin. With traditional costing methods, companies know only their overall margins. The truth is that some products are winners, and some are losers. Accurate costs are essential for answering this question;
2. New production techniques have increased the indirect costs. The indirect cost constitute more and more of the total cost; and
3. The costs associated with bad decisions that result from inaccurate cost determination are substantial. Companies with accurate cost information have a huge advantage over those with inaccurate cost information.

From the results analysis of this research, decision makers benefit in the following ways from implementing ABC in the investment-evaluation process:

1. Enhanced understanding of the cost structure of a company’s future services;
2. Enhanced quality of cost data used in decision-making processes;
3. Good cost information for a company’s future services; and

4. Better data for decision-making processes than is provided by traditional costing systems.

The author concludes that using the ABC method in investment evaluation may not be a “must” but it is definitely a “plus”. Managers are encouraged to adopt the ABC method for cost analysis in the investment-evaluation stage.

6.3 Synergy Effect Between QFD and ABC in Capital Investment Evaluation Stage

From the above, we know that QFD and ABC are pluses in the capital investment evaluation stage. When implemented together in the investment-evaluation processes, will there be any synergy effect? Briefly, QFD should be used to identify key processes, then ABC to cost the identified key processes. From the results analysis of this research, 70% of the members of the expert panel agree or strongly agree that there is a synergy effect between QFD and ABC when they are implemented in the investment-evaluation processes. See Section 5.2.2.4 for details.

The Integrated Model in this research may not be “the” model for capital investment evaluation, but it is a good capital-investment evaluation model with the power of QFD and ABC.

7. Limitations of This Research and Future Researches

7.1 Limitations of this research

There are limitations to this research:

- Limited samples.

QFD and ABC are not commonly both known by an individual in the PCB-fabrication industry. A large-scale survey within the PCB-fabrication industry is not practical. In this dissertation, the author uses interview & survey with members of expert panel instead of large-scale survey. There are 10 industry experts on the panel. Because of the limited sample size, the survey result will be statistically tested with t-test.

- Tutorials conducted

As mentioned in the above, QFD and ABC are not commonly both known by an individual in the PCB-fabrication industry. The author had to give tutorials about QFD or ABC to interviewees, if necessarily. The quality of the tutorials may bias the result.

- Assume that the related processes are known and studied

In the definitions of three indices defined in this research, the author assumed that the related processes are known and studied. For some venture capital cases, only concepts of products or services are available. The related processes are not well defined or even defined at all. In this kind of case, the reliability of the decisions made may be questionable. To solve this, the author encourages decision makers to do more research on the related processes before make the final decision. If one has to gamble, one should gamble wisely.

In this dissertation, the author does not attempt to say that the Integrated Model is ***the*** model. Instead, it is a good model for generating good supporting data for the final decision.

7.2 Future Researches

There are a few research opportunities for academic or industrial researchers from this research:

1. Is the Integrated Model applicable to other industries?

Different industries have different evaluation criteria for investment. It will be worthwhile to study the difference in evaluation criteria among industries. Also, with these differences, will experts in other industries agree on what the experts in this research agreed on? If they do, then the Integrated Model could be a reference model under the topics of "Capital-Investment Evaluation Models."

2. Conducting research on the right formula used to define the three indices.

In this research, the author uses logical relationships, not mathematical relationships, to indicate the relationships between the internal processes, or ECs, and customers' requirements. Also, the author uses the logical relationship to indicate the relationship between market performance and how well the customers' requirement are met. These logical relationships were very straightforward from view of practice. The mathematical formulas or functions for these relationships and how they impact the results will be good topics for research.

3. The differences of opinion about the Integrated Model between managers at different levels

In this research, members of the expert panel are invited randomly. The only qualification is that they should have been involved in their company's capital investment evaluation processes. They do not have to be involved in whole process. The size of the capital investment is not limited. Their positions in company is not specified. So, it will be worthwhile to conduct another research to study the attitude difference about the Integrated Model between managers at different levels.

4. Conduct post survey about individual's knowledge about QFD and ABC

In this dissertation, tutorials of QFD and ABC are conducted. A post survey about individual's knowledge about QFD and ABC can be conducted to study the difference in pre-tutorial and after-tutorial.

Appendix A

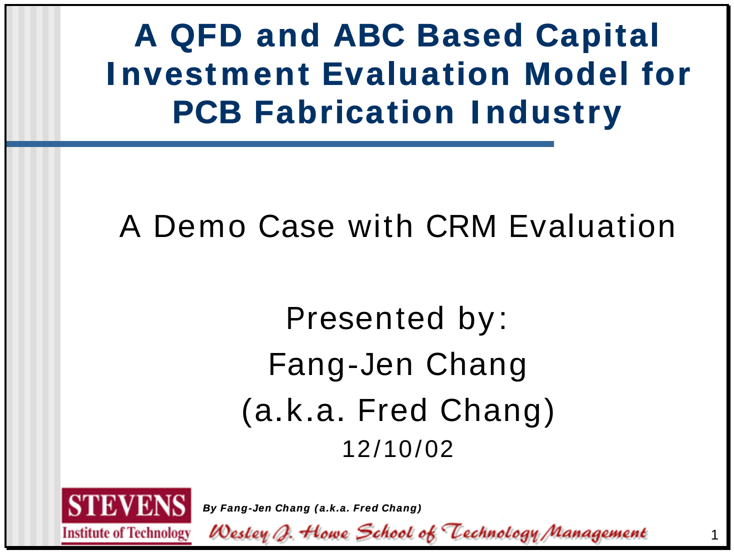
Presentation Package of Interviews & Survey of the Experts

Presentation Slides of Model Description

- English Version

(Note: Chinese version is available on request from the author)

Slide 1


A QFD and ABC Based Capital Investment Evaluation Model for PCB Fabrication Industry
A Demo Case with CRM Evaluation
Presented by:
Fang-Jen Chang
(a.k.a. Fred Chang)
12/10/02
STEVENS
Institute of Technology
By Fang-Jen Chang (a.k.a. Fred Chang)
Wesley J. Howe School of Technology Management
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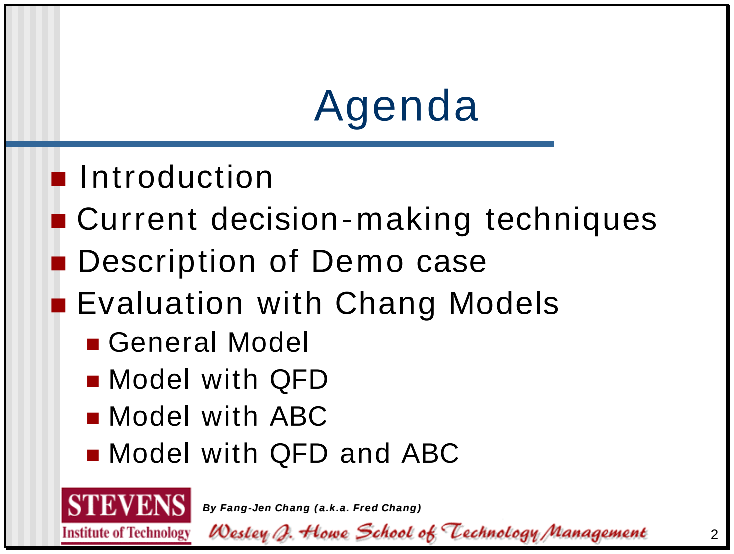
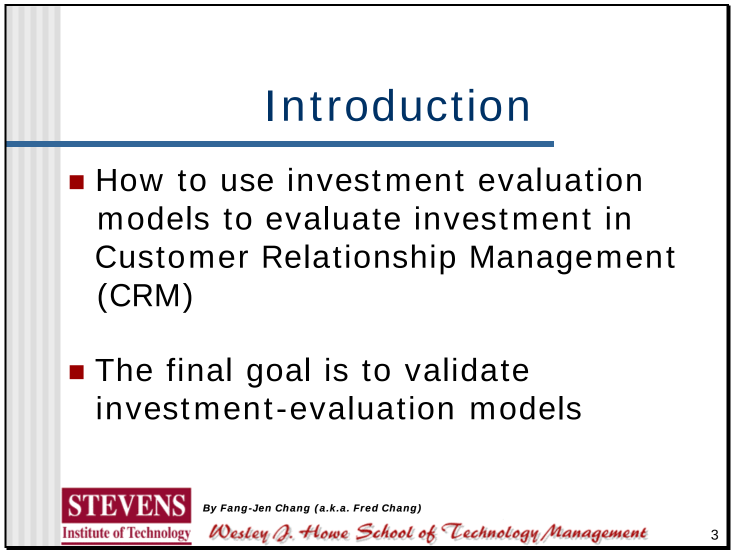
Slide 2



In this presentation, I will go through:
Describing briefly why companies invest;
Then the techniques can be used in capital investment decision-making;
Demo case background;
Evaluation with Chang Models;
- At the end of each model demo, a survey will be conducted

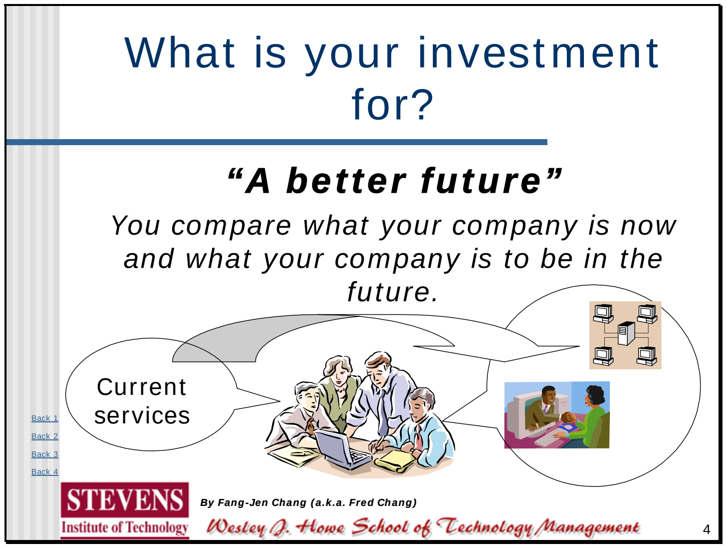
The four Chang models are high-level models. In each relative process in the model, current analysis techniques used in a company can apply. The major objective of this research is to study how Quality Function Deployment (QFD) and Activity-Based Costing (ABC) could help to refine decisions on capital investment. They may be treated as guidelines.

Slide 3



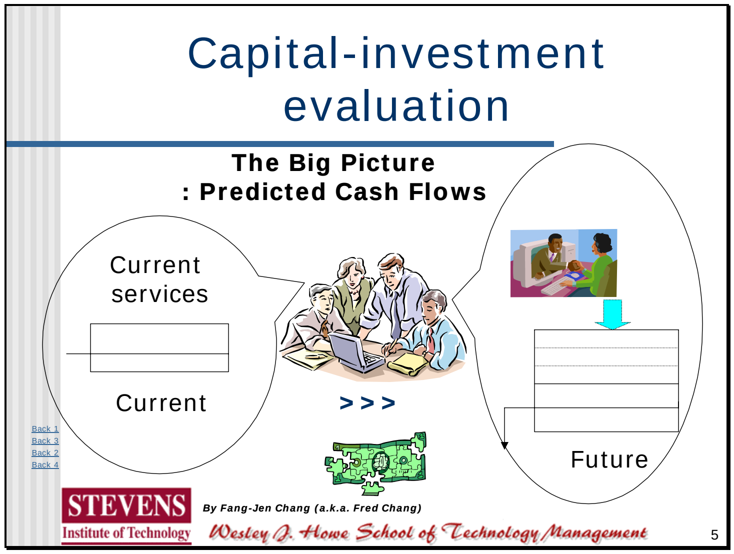
To demo how the models work, a short case study will be used. In the case, a PCB-fabrication firm is considering investing in a Customer Relationship Management (CRM) system.
The final goal is to validate models and benchmark between them.
All models in this research are high-level models. They are as high as guidelines that advise users what major processes should be undertaken. For example, models tell users should to do an economic study. But they do not tell users which economic-study method should be used. Users could plug whatever economic study methods they are using currently into the model. This way, flexibility and compatibility can be maintained.

Slide 4



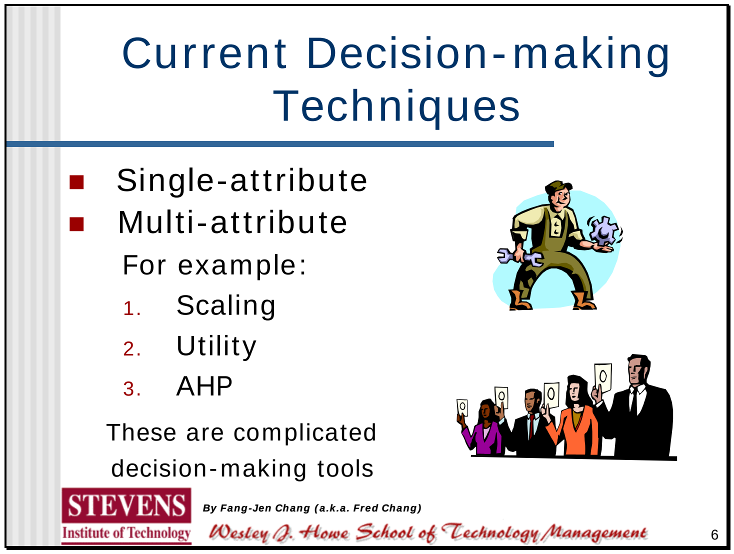
Before we start the demo, let me briefly talk about capital investment. The question here is: Why does your company invest?
What your company should be in the future will let you, as an executive, have more confidence in better performance. In other words, investments should make your company more competitive in the future. This is what investments are for.
In each investment, your company expects to bring in new revenues or cost-savings. To evaluate an investment, you compare the company’s future services and current company’s services. The future company’s services are what change the current ones to by investing.

Slide 5



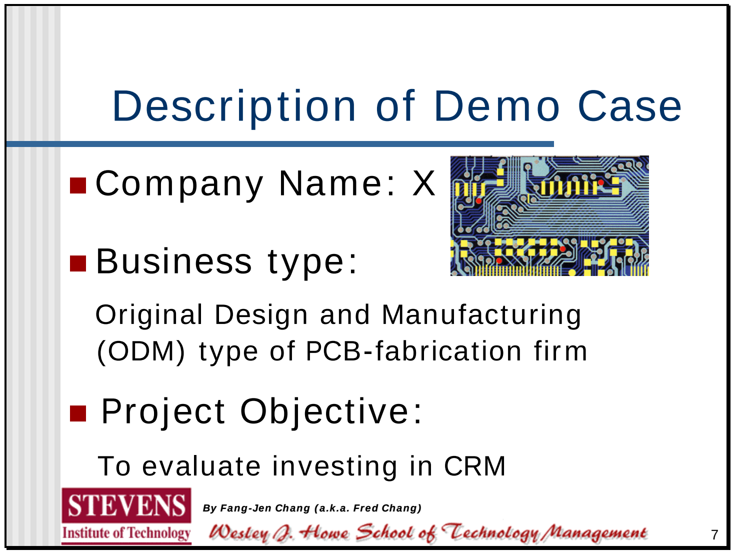
How do companies evaluate investments?
Based on the survey conducted by Farragher in 1999, 86 % of respondents use discounted cash flow. 63% use risk-adjusted discount rates, and 37% adjust the forecasted cash flows. 55% of the respondents require a quantitative risk assessment and prefer sensitivity analysis and scenario (high-average-low) analysis.
Each individual investment is expected to bring in new cash flows.
How can you be sure that all cash flows are as you predicted? How much confidence do you have?

Slide 6



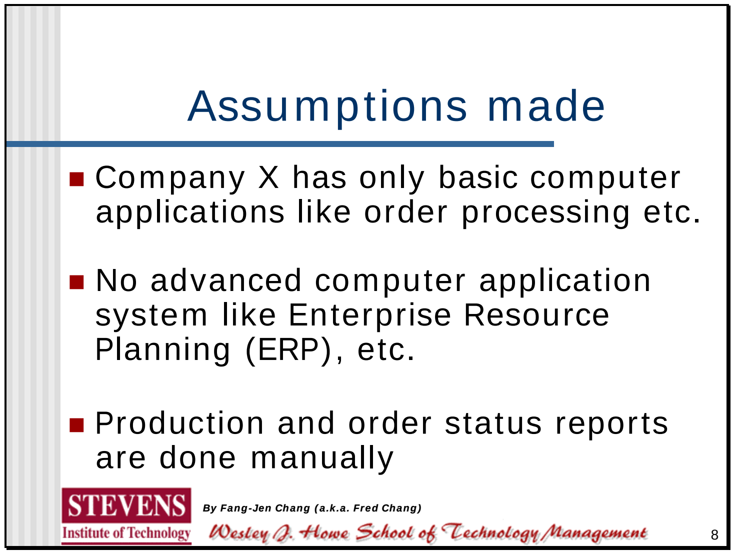
For single-attribute:
For capital projects that focus on a single objective with little or no uncertainty, a single individual could has the power to make decisions based on a single attribute.
In these cases, there is no strategic consideration involved. The relationships between predicted cash flows and the single objective are clear. Decision makers could use the single attribute to evaluate the capital project.
When a capital project focuses on multiple objectives, then multiple attributes should be used for evaluation to ensure that all predicted cash flows close to what are predicted.
But most capital projects involve multiple objectives. To make decisions in a multiple-objective case, multiple-attribute analysis techniques are helpful, for example, AHP, scaling, and utility functions. These techniques all result in a single number that a decision can be based on . If you are interested in these techniques, we can talk about them later.

Slide 7



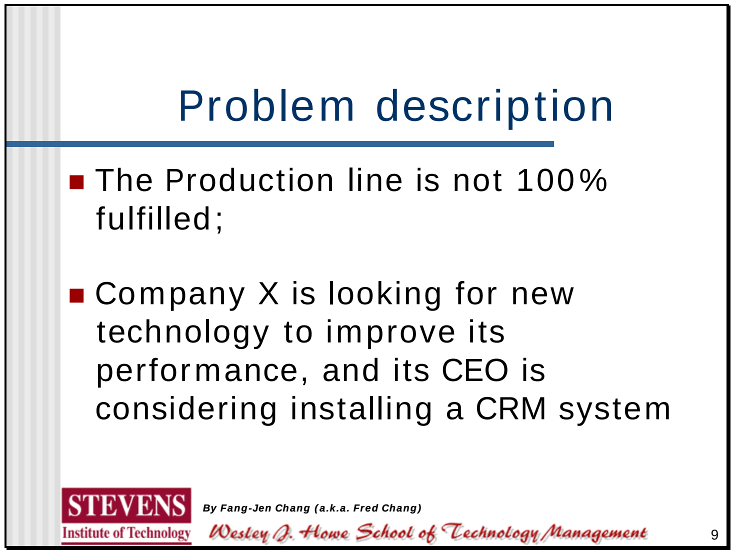
A company named X will be studied. It is an ODM PCB-fabrication firm. And CRM will be the project to be studied.

Slide 8



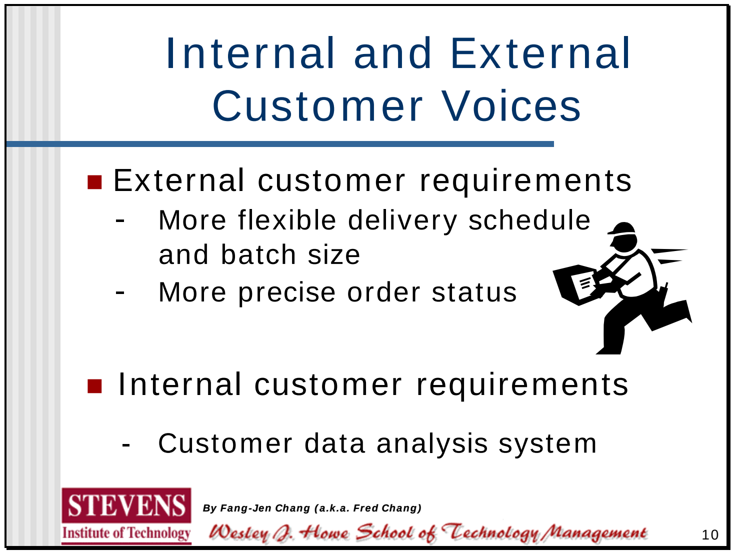
The assumptions in this case are as listed on this slide.

Slide 9



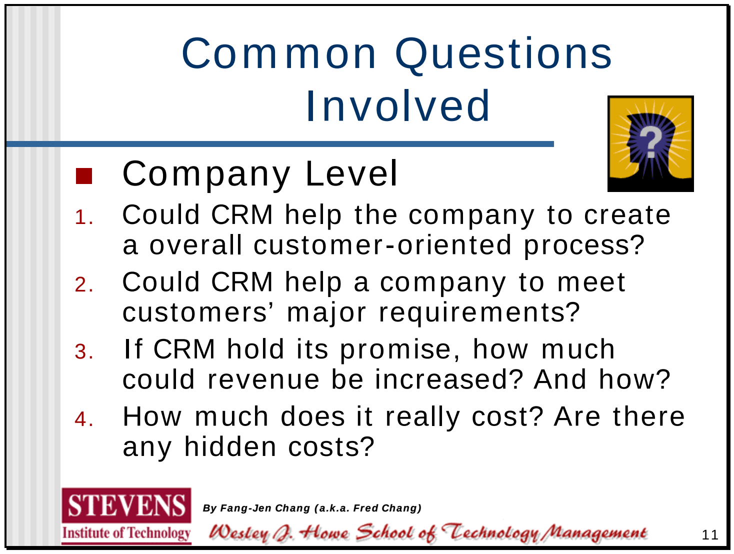
This slide shows the problem company is facing currently. The problem is: production line is not 100% fulfilled.

Slide 10



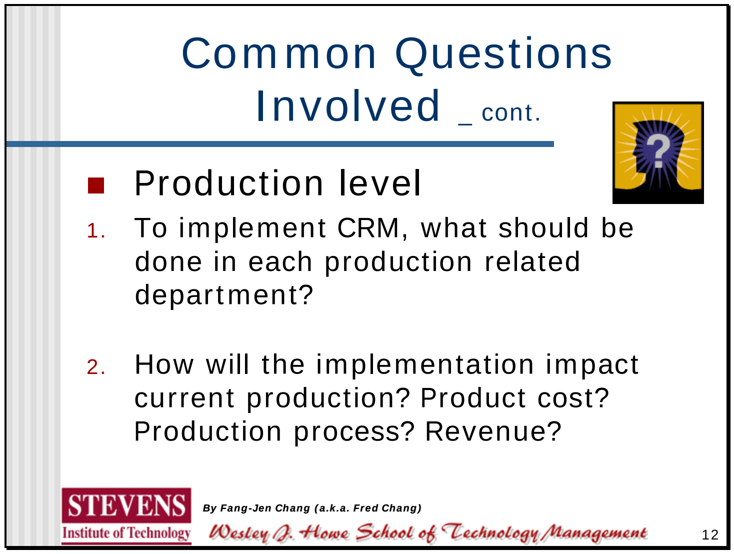
This slide shows what customers have requested recently and also, what the company's staff has suggested.
In the real world, these are not whole set of requirements. But these are a set of reasonable assumptions for the demo purpose.

Slide 11



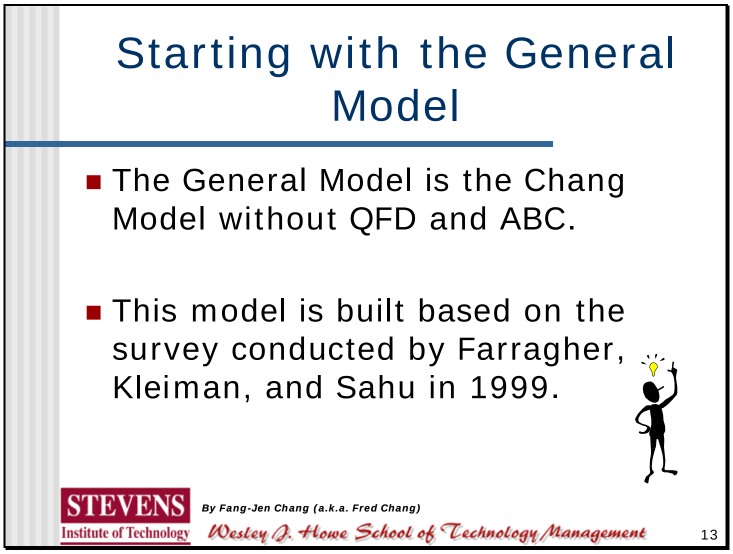
Based on the customers' requirements and the targeted new technology , the company comes up with some questions as shown on this slide and the slide that follows. Although there are many solutions to answer the questions, for demo purposes we assume that the targeted new technology in the demo case is Customer Relationship Management (CRM). This slide shows the questions involved at the company level.

Slide 12



This slide shows what is involved at the production level.

Slide 13



How are the questions in the previous slides answered? Let us start with the general model. The general model is constructed based on the survey conducted by Farragher, Kleiman, and Sahu. They surveyed 379 companies in the Standard and Poor's Industrial Index.

As suggested by Gallinger in 1980, and Gordon and Pinches in 1984, the capital investment system should encompassed seven activities:

Strategy analysis

Establishing investment goals

Searching for investment opportunity

Forecasting investment cash flow

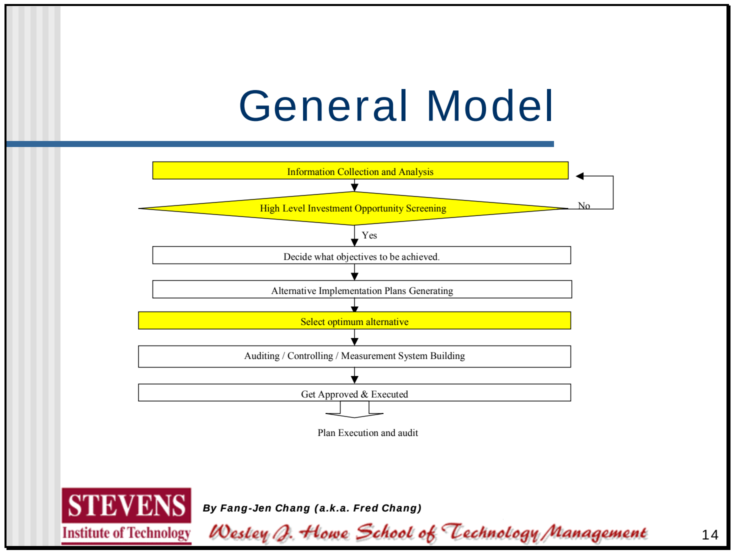
Risk-adjusted evaluation of forecasted cash flow

Decision making

Implementation of accepted opportunities post-audit performance

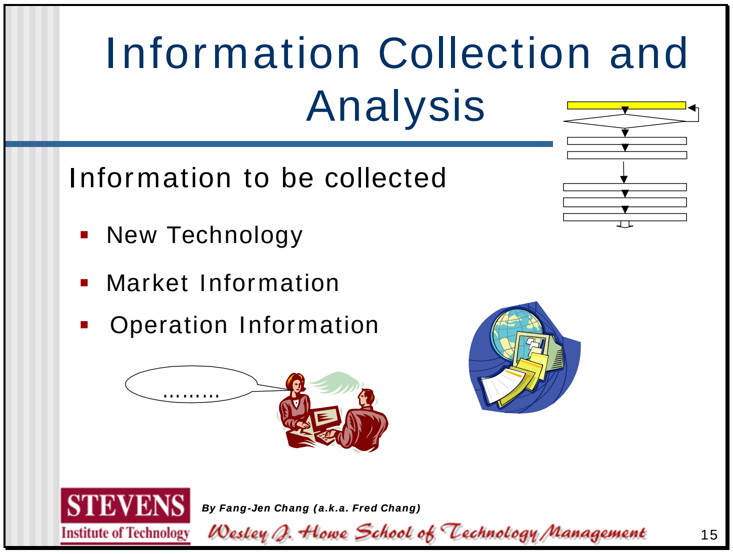
Again, all models in this research are high-level models. They are all based on results of surveys conducted by the above researchers. Later on, I will present how to integrate Quality Function Deployment (QFD) and Activity-Based Costing (ABC) into the General Model.

Slide 14



Please refer page 1 in Attachment 2, detailed description of models, for details. In the following slides, I will describe the details of these processes, which are highlighted. These highlighted processes will used to benchmark models.

Slide 15



Process 1 Information Collection and Analysis

- New Technology

A company looks for new technology to improve market or operation performance. In this case, the company is thinking about Customer Relationship Management (CRM) "**Customer relationship management** is the superset of business models, process methodologies and interactive technologies for achieving and sustaining high levels of retention and referrals within identified categories of valuable and growable customers" - Mei Lin Fung, a contributor at CRMguru.com.

- Market Information

Market information should be the company's source of improvement. For example, customers want more flexible delivery schedules and batch sizes;

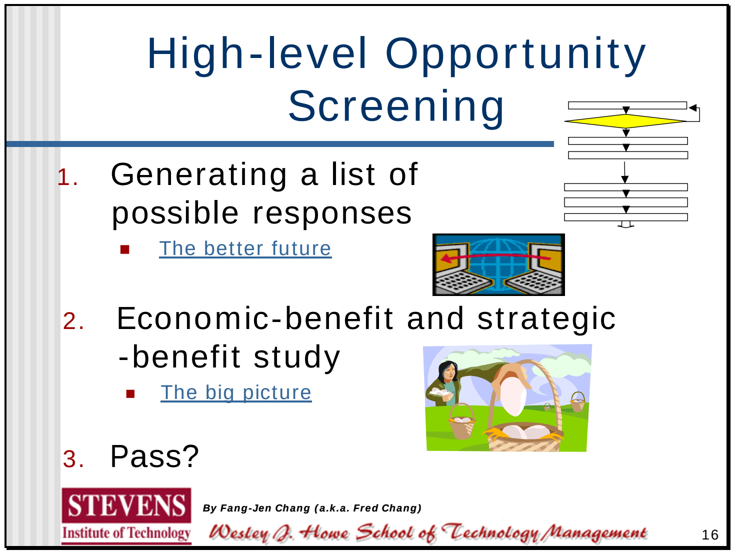
- Operation Information

Operation information is also a source of performance improvement. Sometimes, it is referred as the "internal customer voice". After collecting all information, company starts study what impacts could have.

- Impact Study

After collecting all information, company starts studying what impacts it could have. Information then may be passed through all related department.
In this case, what impacts will there be if the company does not meet customers' requirements for delivery schedules and batch sizes? Obviously, the company will lose current customers and revenue.
Based on the company's study, a list of impacts will be generated.
After that, decision-makers have to think about how CRM can help to solve all the occurring problems.
Please see attachment for details of the Information collection and analysis process.

Slide 16



Process 2:High-level opportunity Screening

Based on the list of the impact of customers' requirements, the company generates related action plans to respond to each impacts. Normally, each related department will be asked to study what will be involved based on each response. And how much does it cost? Each action plan will be studied. How much economic benefit will the company have? What strategic benefit will company have?

For economic studies, the company has to estimate related cash flows. In this process, decision-makers' experience is key. Based on their experience, they judge whether the future services will result in expected related cash flows. Also it will be checked whether there is any violation of a company's strategies or financial policies. Also included in this process should be risk-adjusted evaluations of forecasted cash flows, such as using risk-adjusted discount rates or adjusting the forecasted cash flows, and risk assessment, such as sensitivity analysis or scenario analysis.

For strategic benefit, decision makers have to judge whether the related response actions have any extra strategic benefit or could enhance current strategies.

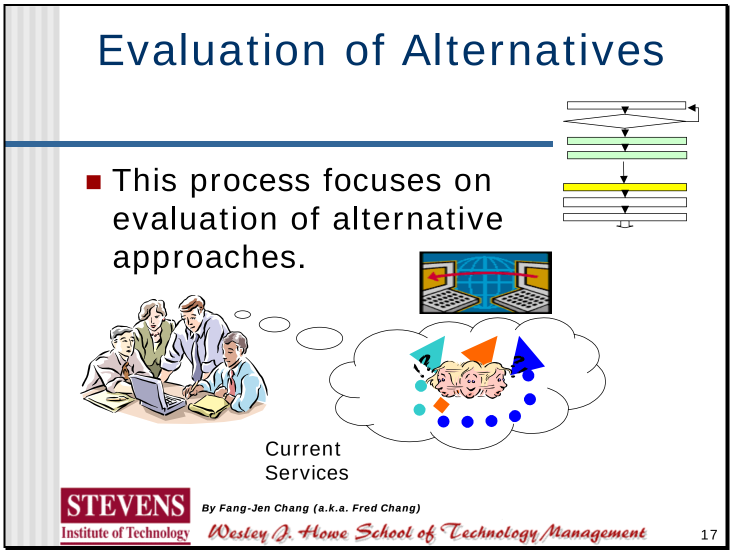
Pass?

Each individual action plan will be evaluated based on economic and strategic studies. Then a "Pass" or "Fail" will be assigned. Also to be checked is whether there will be any synergy effect of combining some of these action plans.

Could CRM cover or some of the action plans? Will there be a synergy effect? With the ballpark estimation of CRM, decision-makers re-estimate the economic study based on the "big picture." Decision makers also have to check against current strategies whether there is any violation or not.

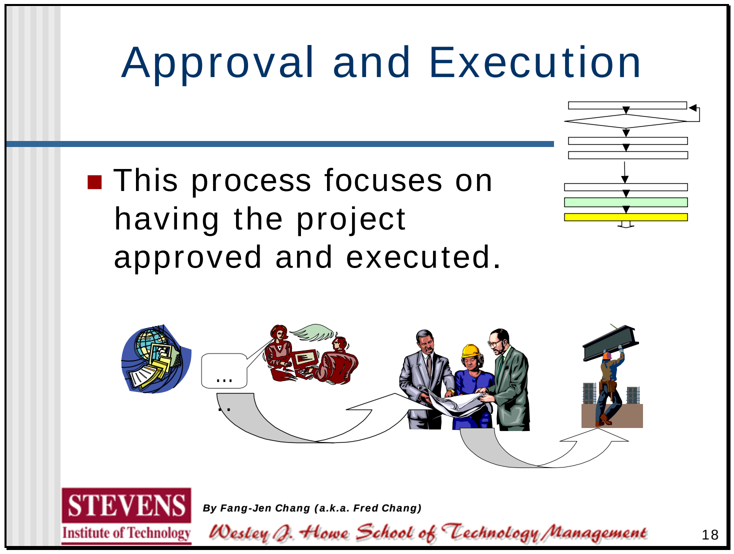
Please refer to the attachment for details.

Slide 17



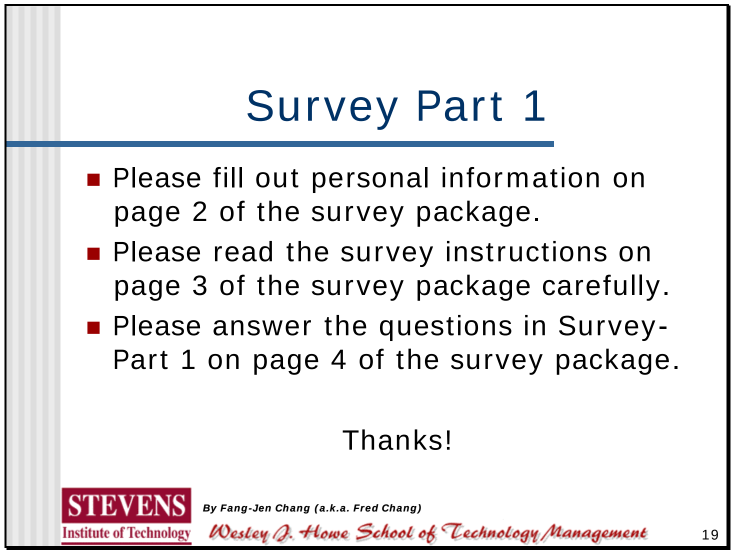
Process 3: Deciding what objectives are to be achieved
Once a action plan has passed evaluation, then
Listing possible objectives is to generate the objectives that could be or have to be achieved according to each response action. These objectives will be used as measures for matching responses.
Checking against current company's objectives is used to detect whether there is any objective that is overlaid or against current company's any objective.
Evaluating objectives is not only used to check whether the listed objectives are practical or not, but also to set an improvement direction for each objective.
The last sub-process in this process is to prioritize these objects. The priority of objectives will be used to evaluate alternative implementation plans.
Process 4: Generating of alternative implementation plans
To accomplish selected action plans and objectives, high level alternative implementation plans, or approaches, will be generated. For example, **outsourcing** the CRM project.
Process 5: Selecting the optimum alternative
This process is to evaluate alternative approaches to the installation of CRM. Decision makers could use different evaluation techniques like AHP to proceed with the evaluation.

Slide 18

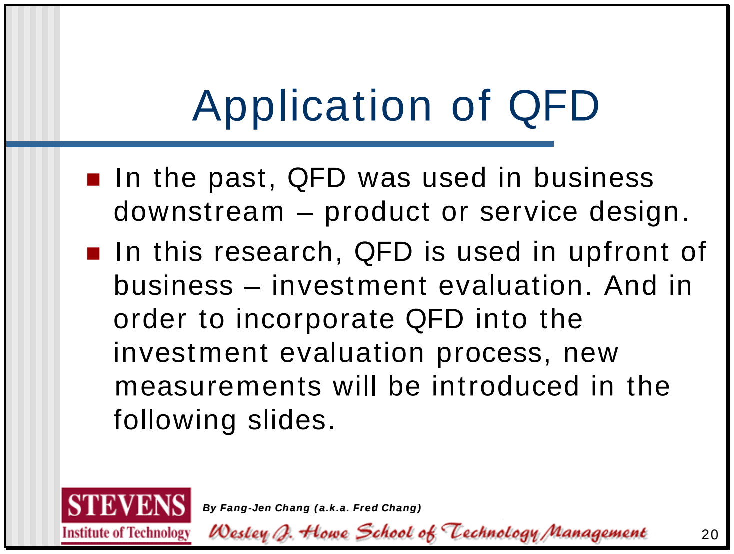


Process 6: Auditing/controlling/measurements system building
In this case, the measurements could be customer satisfaction rate, average response time to customer requests, and average accuracy of order status, etc.
Process 7: Approval and Execution

Slide 19

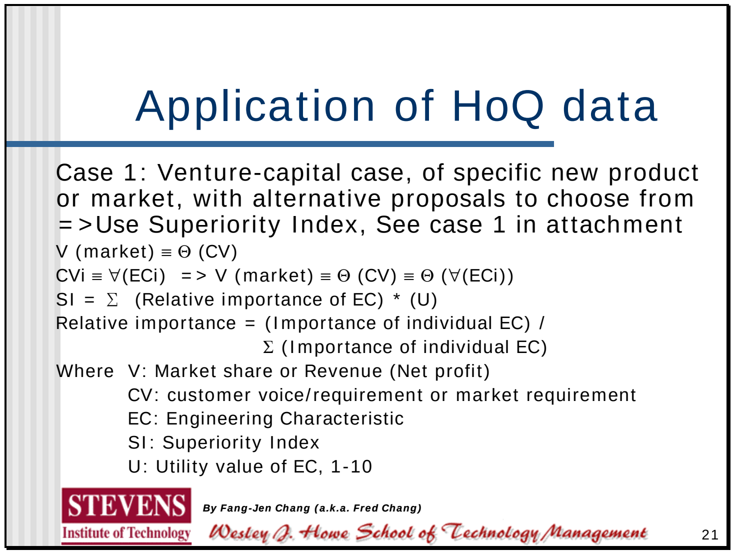

Survey Part 1
Please fill out personal information on page 2 of the survey package.
Please read the survey instructions on page 3 of the survey package carefully.
Please answer the questions in Survey-Part 1 on page 4 of the survey package.
Thanks!
STEVENS
Institute of Technology
By Fang-Jen Chang (a.k.a. Fred Chang)
Wesley J. Howe School of Technology Management
19

Slide 20



In the past, QFD was mostly used in product or service design. Later on, in the 1990's, many companies used QFD to deploy their strategy.
In this research, the author will show that QFD can be used as a tool to assist decision-makers in making better decision in multi-element decision-making process.
In order to implement QFD in the investment evaluation process, in this research, three indices were defined for three different cases. The next few slides will show you how they are defined.

Slide 21



In a venture capital case, with a specific product or market, with alternative proposals to choose from, the Superior Index should be used for final decision. The Superior Index is the individual relative importance of each EC multiplied by the utility value of EC. Then, they are summed up.

V (market) ≡ (CV)
CVi ≡ (ECi)
where V: Market share or Revenue (Net profit?)
CV: customer voice/requirement or market requirement
EC: Engineering Characteristic

V (market) ≡ (CV)
≡ ((ECi))
≡ (ECi)

SI = Σ (Relative importance of EC) * (Utility value of EC)

Relative importance = (Importance of individual EC) / Σ (Importance of individual EC)

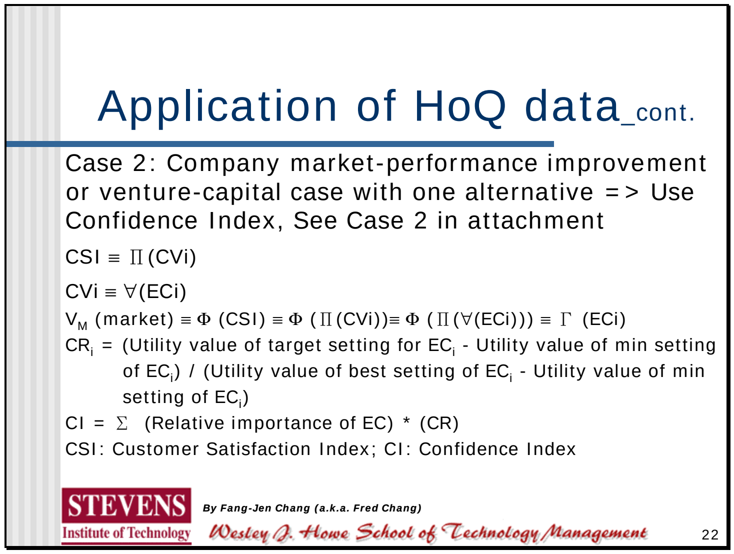
SI: Superior Index

The final decision will be based on the Superior Index. The alternative with the highest Superior Index wins.

The utility value of EC is based on the evaluation according to each alternative's performance of specific EC.

The utility value of each EC of the individual company is assigned based on utility function, scaling method, or AHP.

Slide 22



If this is done for company market-performance improvement or venture-capital case with one alternative, then:

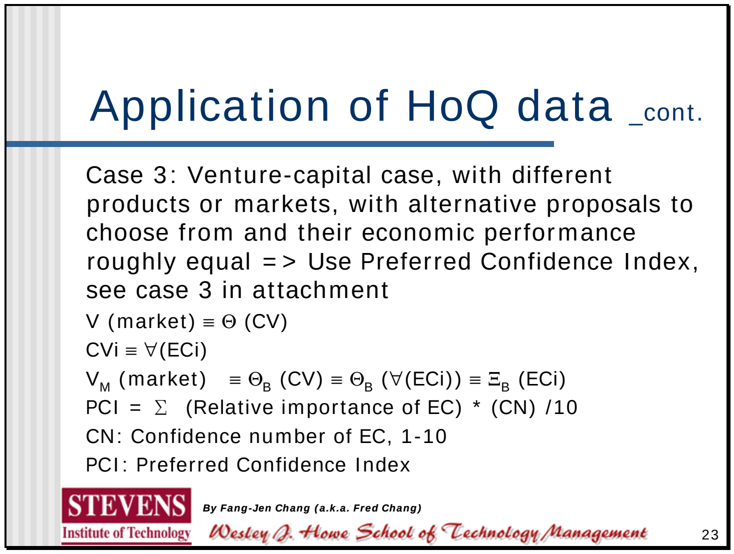
CSI $\equiv \Pi(CVi)$
CVi $\equiv (ECi)$
where CSI: Customer Satisfaction Index
CV: customer voice/requirement or market requirement
EC: Engineering Characteristic
V (market) $\equiv$ (CSI) V: Market share or Revenue (Net profit?)
$\Rightarrow$ $V \equiv (\Pi(CVi))$
$\Rightarrow$ $V \equiv (\Pi((ECi)))$
$\Rightarrow$ $V \equiv \Gamma(ECi)$
V_M (market) $\equiv \Phi_B\ (CV)$
$\equiv \Phi_B\ ((ECi))$
$\equiv \Gamma_B\ (ECi)$

V_M: Target market share could be achieved with **minimum** setting of ECs.
Note: The minimum setting is based on survey or judgment by study team.

CR = (Target setting for EC) / (Medium setting of EC)
where CR: Confidence ratio of EC
Note: Medium setting of EC is the setting of the market player with average performance.

CI = Σ (Relative importance of EC) * (CR) CI: Confidence Index
If the CI is less than 1, the proposal should be rejected. If the CI is great than 1, the proposal may be accepted.

Slide 23



If this is a venture capital case, with different products or markets, and alternative proposals to choose from and their economics and strategy performance roughly equal, Confidence Index should be used for the final decision. The individual relative importance of each EC is multiplied by the confidence numer of EC. Then they are summed up. Based on the sum, the better one is chosen.

$$V \text{ (market)} \equiv \text{(CV)}$$
$$CVi \equiv \text{(ECi)}$$

Where V: Market share or Revenue (Net profit?)
CV: customer voice/requirement or market requirement
EC: Engineering Characteristic
Θ : Function of market that relates customer voice to market share.

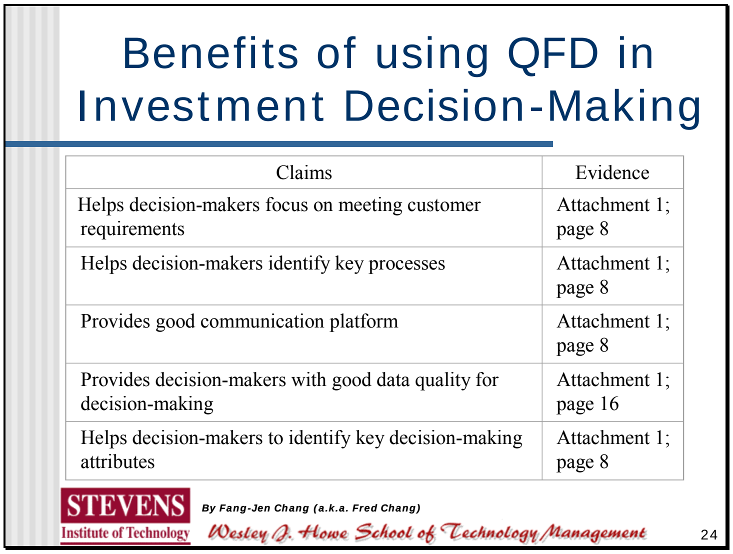
V_M (market) ≡ Θ_B (CV) ≡ Θ_B ((ECi)) ≡ Θ_B (ECi)

V_M: Target market share could be achieved with **minimum** acceptable setting of ECs.
Note: The minimum setting is based on survey or judgment by study team.

PCI = Σ (Relative importance of EC) * (CV) / 10

PCI: Preferred Confidence Index, Best value is 100
CN: Confidence number. 1-10: "1 " means lowest confidence, "10" means highest confidence. Confidence number is the number assigned to each EC based on its setting. If the setting is much better than the minimum setting, number "10" will be assigned. When the setting is closer to the minimum setting, the lower number should be assigned.
Relative importance = (Importance of individual EC) / Σ (Importance of individual EC)
The final decision is based on PCI. The alternative with highest PCI wins.

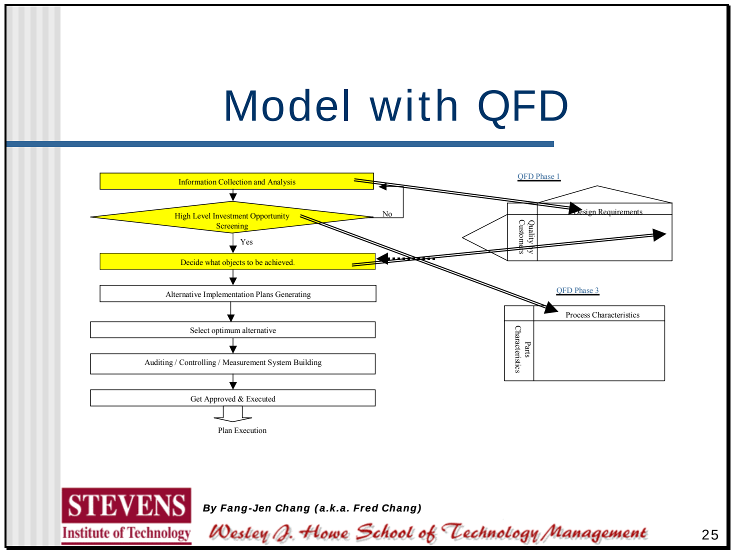
Slide 24



Claims	Evidence
Helps decision-makers focus on meeting customer requirements	Attachment 1; page 8
Helps decision-makers identify key processes	Attachment 1; page 8
Provides good communication platform	Attachment 1; page 8
Provides decision-makers with good data quality for decision-making	Attachment 1; page 16
Helps decision-makers to identify key decision-making attributes	Attachment 1; page 8

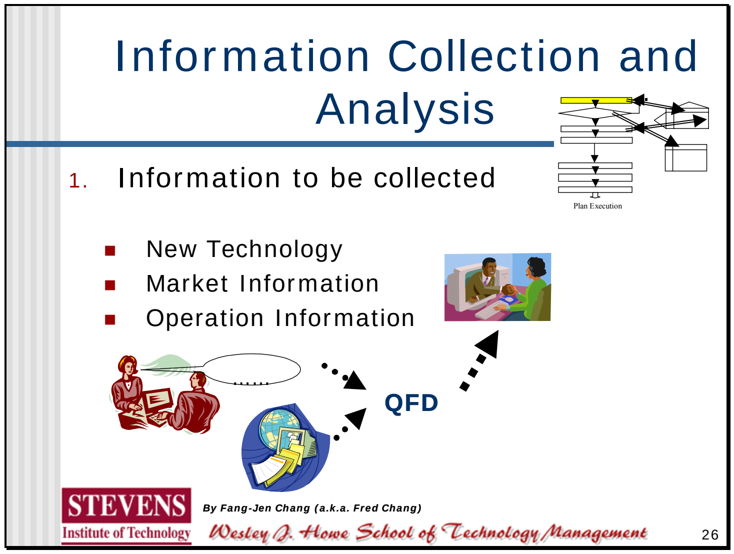
Implementing QFD into the investment-evaluation stage, the user will have the benefits described in this slide. And I will point out each in the following slides.

Slide 25



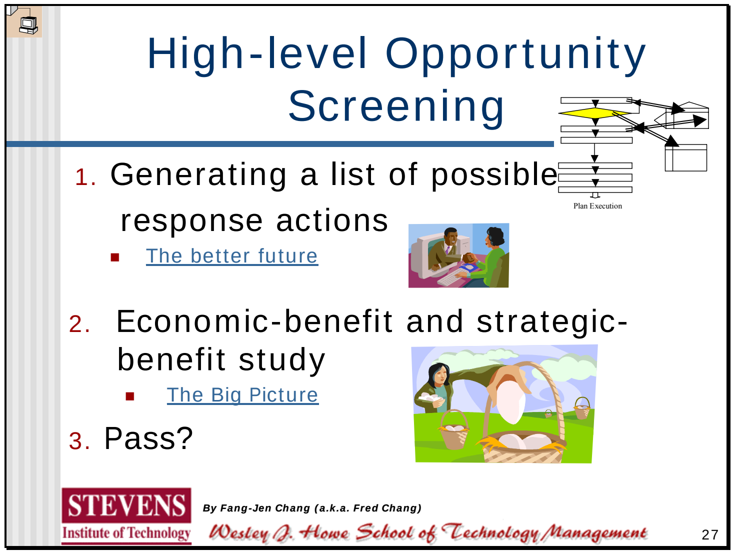
The Chang model with QFD integrates QFD into the Chang General Model.
QFD has been used successfully in product design. With QFD, the product-design team could focus more on the qualities that are defined by the customer. As a result, the product has higher quality, a shorter design-cycle time and is more customer-oriented. In other words, QFD is excellent way to transform customers' requirements into product design.
Now, the company treats its product and the related services as a product, which means that the product PCB is part of the service. How does one use QFD to break down all the related services based customers' requirements. To gain most advantage out of QFD, the decision-making team should include staff from the production department, market department, and IT department. And the staff's knowledge about their process is one of keys to success in the QFD process. As a result, the final decision is more customer-oriented.
The following slides will show you each process in this model.

Slide 26



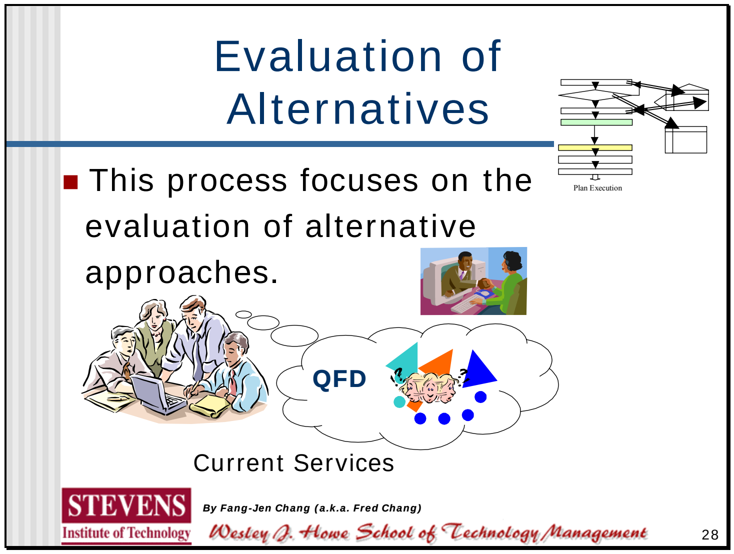
Process 1: Information collection and analysis
1 Company inputs the customers' requirements and operation requirements into the WHATs in the House of Quality (HoQ).
2. Identify the major services related to all these requirements and put them in HoQ's HOWs. Then "importance" between each WHATs and HOWs is assigned. The completed HoQ will be the quality-improvement map and services deployment map to meet your customers' requirements. While completing the HoQ, the company's market position related to each requirement and organizational difficulty in each identified services is assessed, and the weight for each identified service is calculated. With the calculated weight, decision makers can know which services are key factors to success in meeting customers' requirements.
3. Based on this map, new technologies that could help to improve or improve identified processes should be found.
In the demo case, the target is CRM. Please refer page 8 in Attachment 1.
Impact Study
After collecting all the information, company starts studying what impacts there could be. For example, what will the impacts be if the company does not meet customers' requirements for delivery schedules and batch sizes? Obviously, the company will lose some current customers and revenue. Based on the company's study, a list of impacts will be generated. After that, decision-makers have to think about: Could CRM help to solve all the other occurring problems? Please see attachment for details of the Information collection and analysis process.

Slide 27



Process 2: High-level Opportunity Screening
Based on the list of impacts, the company generates the related action plan to respond to each identified service. In each alternative action plan, functions to be included can be found in QFD phase-II's HOWs. **See page 9 in Attachment 1**.
With QFD, decision-makers know that Inventory-report-on-demand and production-report on demand functions are needed to meet the customer requirements – flexible delivery schedules/batch sizes and precise order status. This kind of data will help decision makers to create a clearer picture about future services.
With a clearer picture, each action plan will be studied. How much economic benefit will the company have? What strategic benefit will the company have? Analysis techniques used in the General Model are also applied here.
Pass?
Could CRM cover all action plans or some of the action plans? With the ballpark estimation of CRM, decision makers re-estimate the economic study based on the "big picture". Decision-makers also have to check against current strategies whether there is any violation or not. How real could be the "Big Picture?"
Please refer the Attachment for details.

Slide 28



Process 3: Deciding on objectives to be achieved

Listing possible objectives is used to generate the objectives that could be or have to be achieved according to each response action. These objectives will be used as measures for each response. Some of the key objects, for example, customer-order-and-handling in 4 hours and real time order-status-report could be found in HoQ.

Checking against current company's objects is to detect whether there is any objective that is overlaid with or against current company's objectives.

Evaluating objectives is not only to check whether the listed object is practical or not, but also to set an improvement goal for each objective.

The last sub-process in this process is to prioritize these objectives. The priority of objectives could be used for evaluating alternative implementation plans.

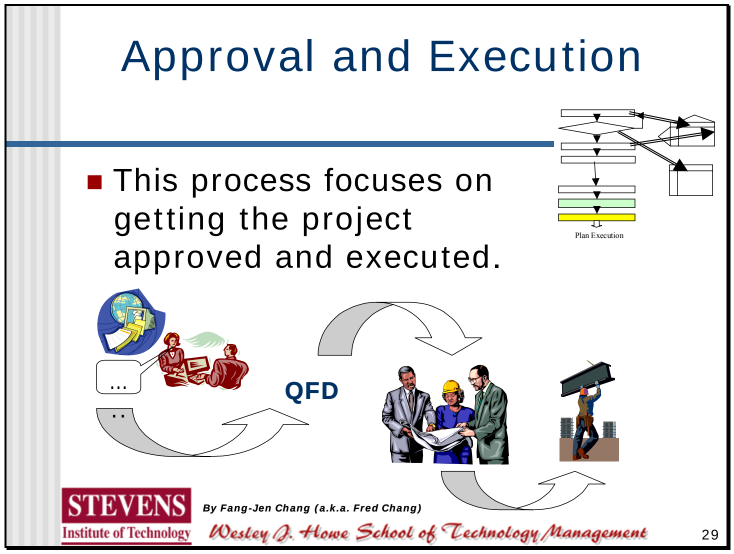
Process 4: Generation of alternative implementation plans

To approach CRM, high-level alternative implementation plans will be generated. In each alternative-implementation plan, what functions should be included in each objective can be found in QFD phase-II's HOWs. These data could be used in defining the process's required functions, for example, outsourcing the CRM project. See page 9 in attachment 1. In the RFP, the HOWs in QFD phase II could be listed as requirements.

Process 5: Selecting the optimum alternative

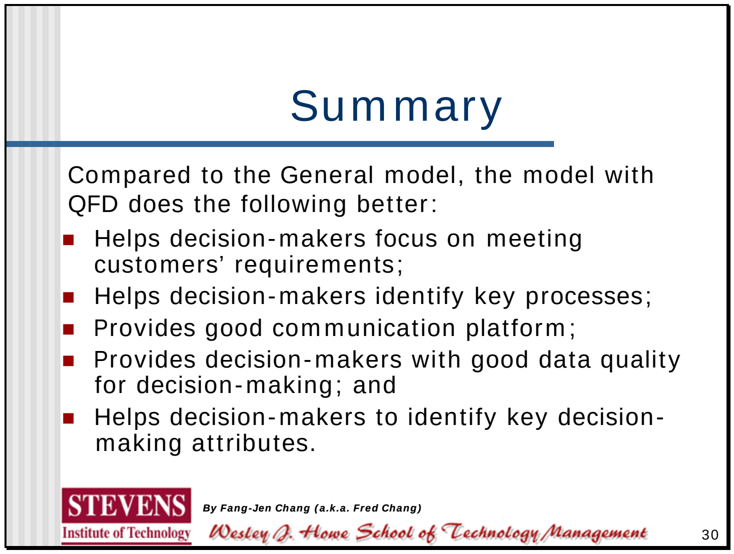
This process is to evaluate alternative approaches to the installation of CRM. Decision-makers could use different evaluation techniques, decision-making techniques like AHP, to proceed the evaluation. The HOWs in QFD phase III, (see page 10 in Attachment 1), could be used as attributes to evaluate alternatives, for example, software creation. The software creation will be evaluated by using man-power, team-member combinations, and time. Now, the decision is that of a high-executive in the company. Once a high-level approach is selected, a related detail-implementation plan follows.

Slide 29



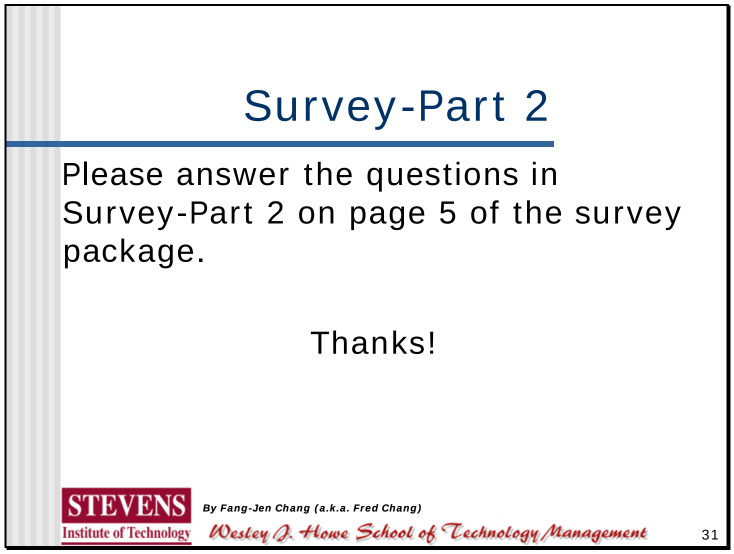
Process 6: Auditing/controlling/measurements system building
In this case, measurements could be as identified key services in HOWs of HoQ, such as customer satisfaction rate, average response time to customer request, and average accuracy of order status. With QFD, decision-makers will know which among these key services are most important to the success of a company's future.
Process 7: Approval and execution
As a result, the final plan focuses on meeting customers' requirements.

Slide 30



Compared to the General Model, the model with QFD could do all that the General Model does and has the advantages listed in this slide.

Slide 31


Survey-Part 2
Please answer the questions in Survey-Part 2 on page 5 of the survey package.
Thanks!
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Slide 32

Benefits of Using ABC in Investment-Decision Making

Claims	Evidence
Enhances decision-makers' understanding of the cost structure of a company's future services	Attachment 1; page 33
Enhances the quality of cost data used in decision-making processes	Attachment 1; page 33
Provides good cost information about a company's future services.	Attachment 1; page 33
Provides better information in the decision-making processes	Attachment 1; page 33

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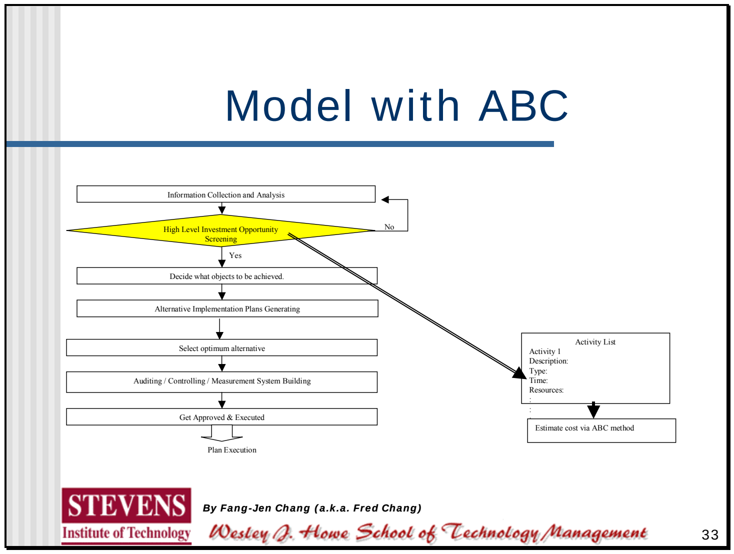
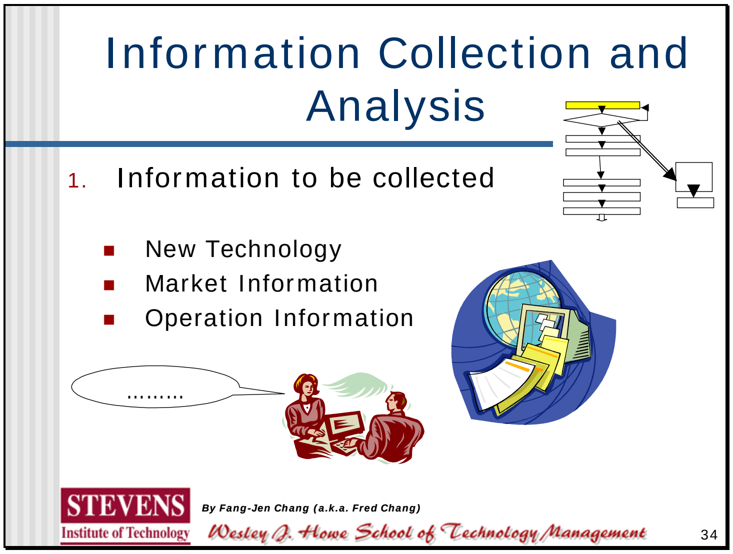
It has been proven by academic and industry practitioners that ABC provides more accurate supporting cost information than a traditional costing system in the production stage. Does ABC also work in the investment evaluation stage? In this research, the author claims that by Implementing QFD into the investment evaluation stage, users will have the benefits described in this slide. And I will point out each in the following slides.

Slide 33



ABC has been proven to provide more accurate price information than a traditional costing system does.
Sometimes, the market depends on one factor only, the unit prices. If this is the case, then each action taken should focus on reducing the cost.
The Chang model with ABC integrates ABC into the decision making process.
The overall process is similar to the General Model. The only process that is different is the High-level Investment Opportunity Screening process. In this process, the company uses the ABC to see how the alternative action plan will impact the unit price. The following slides will show you the detailed process for this model. See page 10 in Attachment 2 for detail.

Slide 34



Process 1: Information collection and analysis

- New Technology

A company looks for new technology to improve market performance or operation performance. In this case, the company is thinking about the Customer Relationship Management (CRM)

"**Customer relationship management** is the superset of business models, process methodologies and interactive technologies for achieving and sustaining high levels of retention and referrals within identified categories of valuable and growable customers" - Mei Lin Fung, a contributor at CRMguru.com.

- Market information

Market information should be a company's source of improvement. For example, customers want more flexible delivery schedule and batch size

- Operation information

Operation information is also a source of performance improvement. Sometimes it is referred to as "internal customer voice".

- **Impact studies**

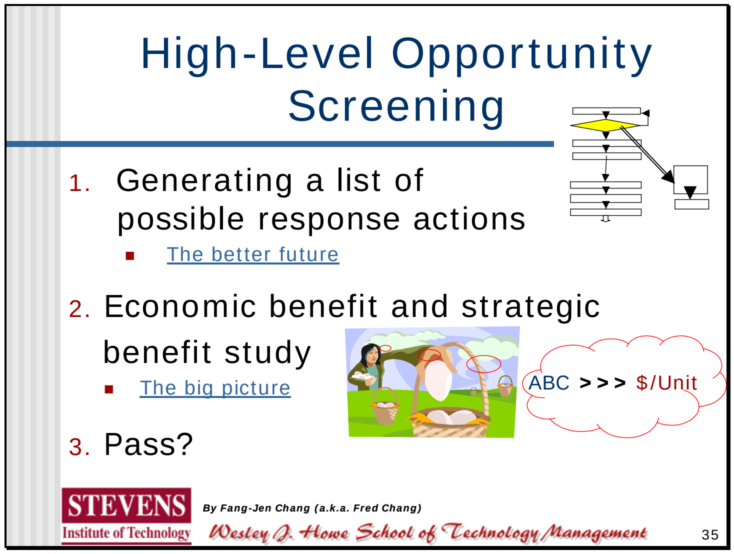
After collecting all the information, the company starts studying what impacts it could have.

For example, what impacts could there be if company does not meet customers' requirements for delivery schedules and batch sizes? Obviously, company will lose current customers and revenue.

Based on the company's study, a list of impacts will be generated.

After that, decision-makers have to think about hoe CRM help to solve all the occurring problems?

Slide 35



Based on the list of impacts, the company generates a related action to respond to each impact. Normally, each related department will be asked to do study based on each response to see what will be involved, and how much it costs? *In each alternative-action plan, the final products' prices will be studied via ABC. How t is the products' unit price impacted by implementing each individual plans?*

Each action will be studied. How much economic benefit will the company have? What strategic benefit will the company have?

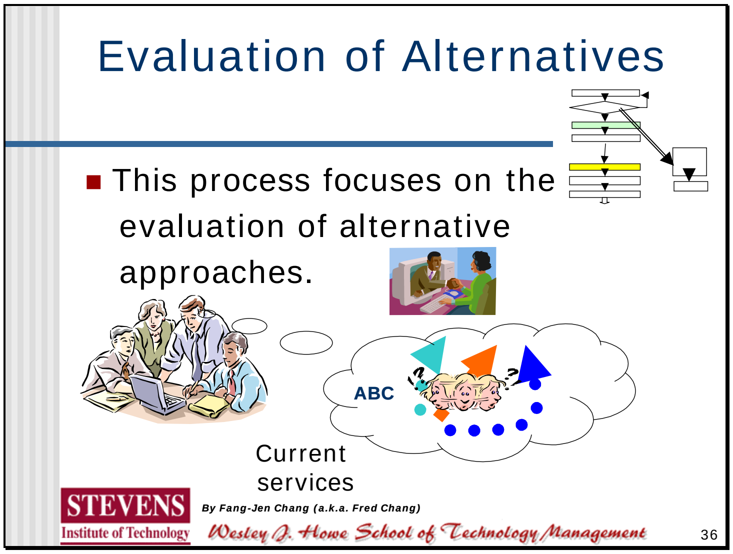
For economic studies, the company has to estimate related cash flows. In this process, decision-makers' experience is the key. Based on their experience, they judge whether the future services will result in the expected related cash flows. Also studies whether there is any violation of the company's strategies or financial policies. For the strategic benefit, decision-makers have to judge whether the related response actions have any extra strategic benefit or could enhance current strategies.

Pass?

Could CRM cover all actions or some of the actions? With the ballpark estimation of CRM, decision makers re-estimate the economic study based on the "big picture". Decision-makers also have to check against current strategies whether there is any violation or not.

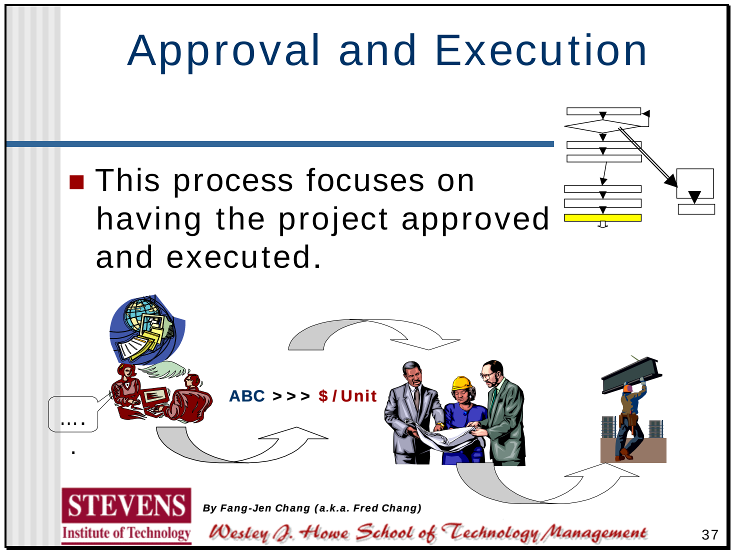
Please refer to the attachment for detail.

Slide 36



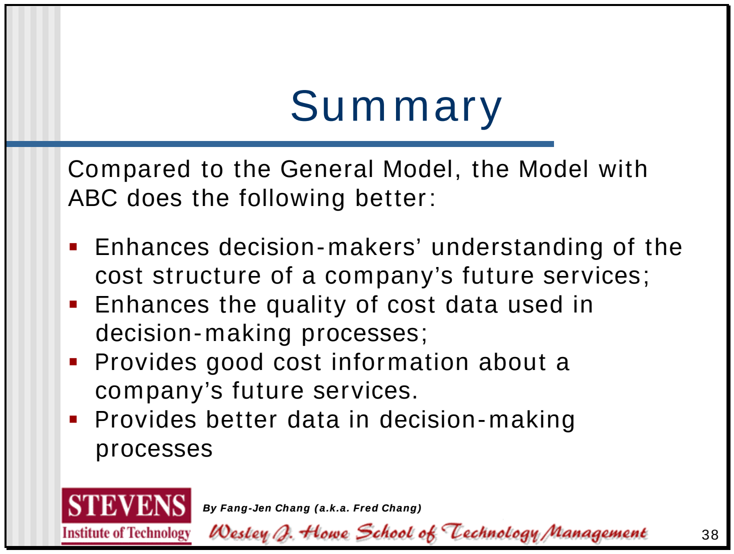
Process 3: Deciding objectives to be achieved
Listing possible objectives is used to generate the objectives that could be or have to be achieved according to each response action. These objectives will be used as measures for each response.
Checking against company's current objectives is used to detect whether there is any object that is overlaid with current company's object or against any object.
Evaluating objectives is not only to check whether the listed object is practical or not, but also to set an improvement goal for each objective.
The last sub-process in this process is to prioritize these objectives. The priority of objectives could be used for evaluating alternative implementation plans.
Process 4: Generation of Alternative implementation plans
To accomplish the selected objects, high-level alternative-implementation plans will be generated, such as outsourcing the project.
Process 5: Select optimum alternative
This process is used to evaluate alternative approaches to the installation of CRM. Decision makers could use different evaluation techniques,like AHP, to proceed the evaluation.

Slide 37



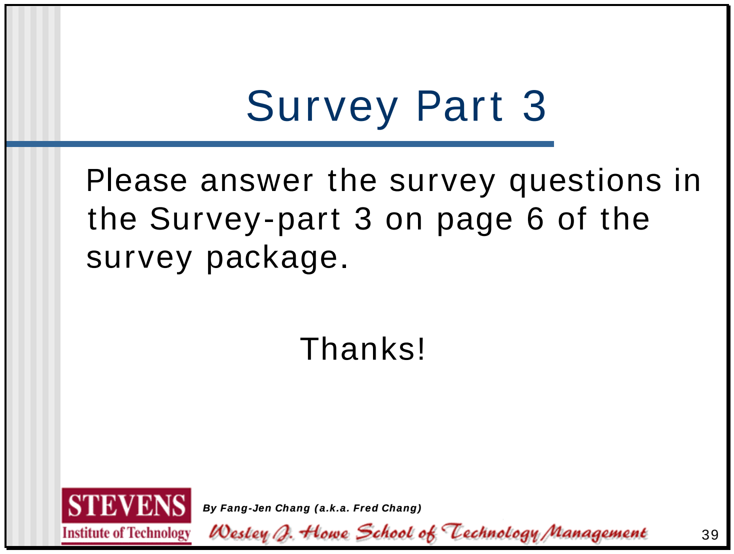
Process 6: Auditing/controlling/measurements system building
In this case, the measurements could be customer satisfaction rate, average response time to customer requests, and average accuracy of order status etc.
Process 7: Approval and Executed

Slide 38



Compared to the General Model, the Model with ABC has the advantages listed on this slide.

Slide 39


Survey Part 3
Please answer the survey questions in the Survey-part 3 on page 6 of the survey package.
Thanks!
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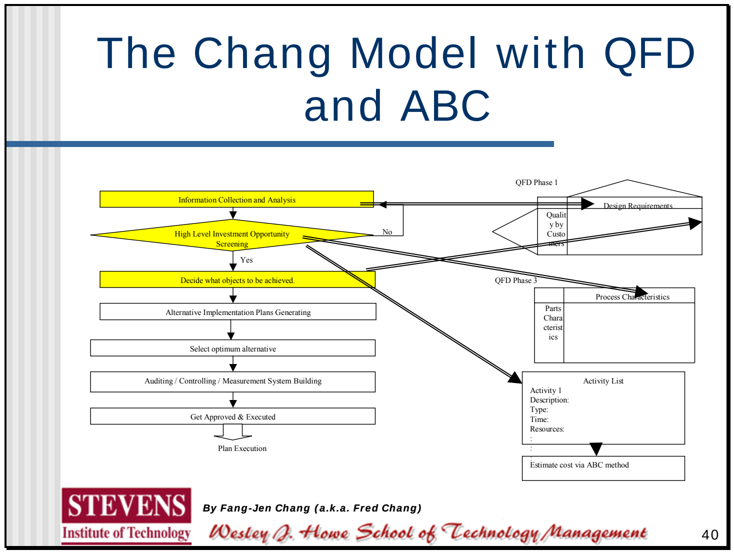
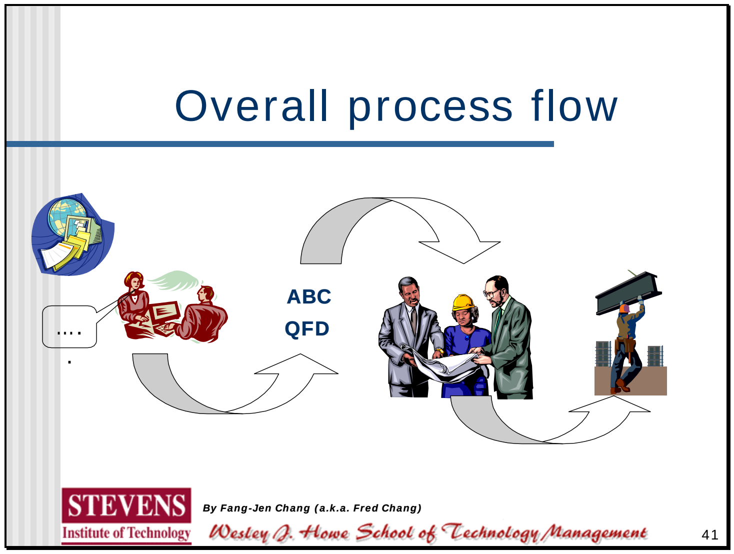
Slide 40



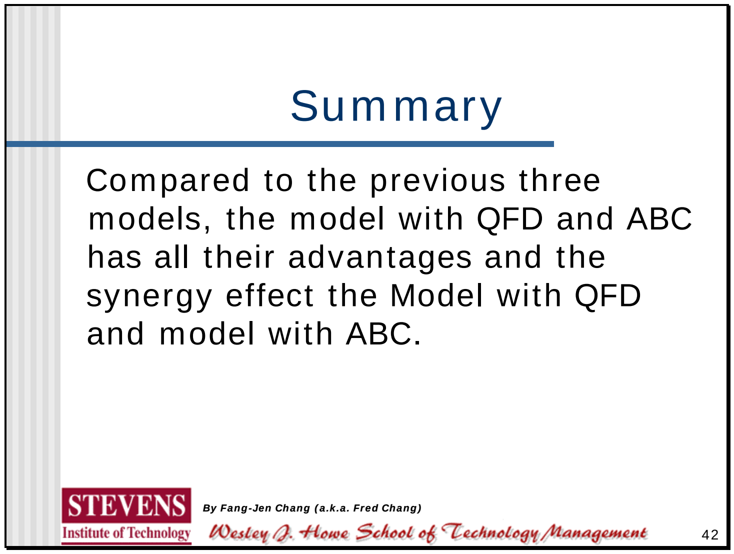
The advantages of integrating QFD or ABC individually into a capital-investment evaluation model has been shown in previous presentation sections. If we integrate both QFD and ABC into a capital-investment evaluation model, a synergy effect can be expected.
The following slides will show the overall process of this model graphically.

Slide 41



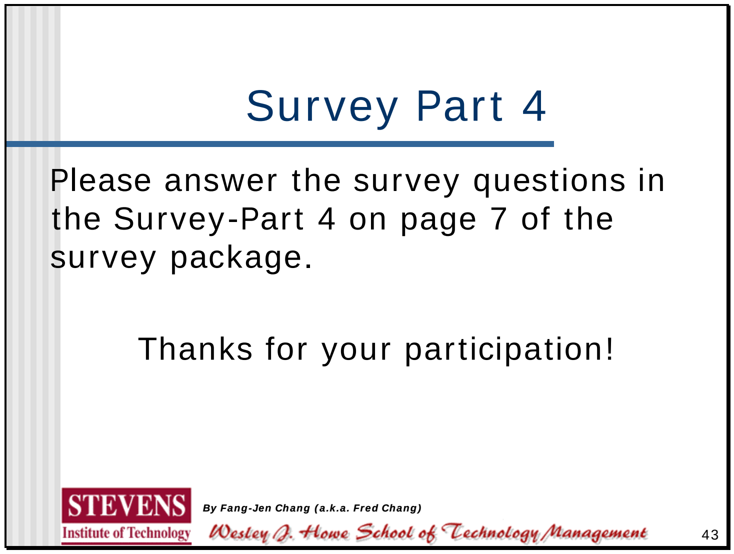
Briefly, the model with QFD and model with ABC are overlaid.
First, do the information-collection process.
2nd, do the high-level investment opportunities screening process with QFD and ABC.
3rd, do the alternative-implementation plans evaluation and have the project approved/executed.

Slide 42



With QFD and ABC, decision-makers could see clearer relationships between customers' requirements and a company's future services, and clear products-price information. A synergy effect of integrating both QFD and ABC into the capital investment evaluation model can be expected.

Slide 43


Survey Part 4
Please answer the survey questions in the Survey-Part 4 on page 7 of the survey package.
Thanks for your participation!
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Presentation Slides of Introduction to QFD

Slide 1

Quality Function Deployment (QFD)

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9/10/02

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Slide 2

Agenda

- History of QFD
- Major successful applications of QFD
- QFD defined
- House of Quality
- QFD 4 phases approach
- Application of HoQ data
- Summary

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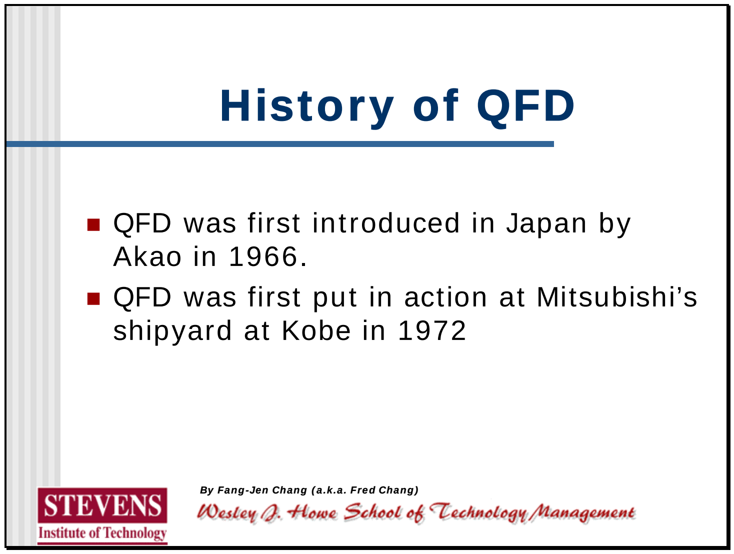
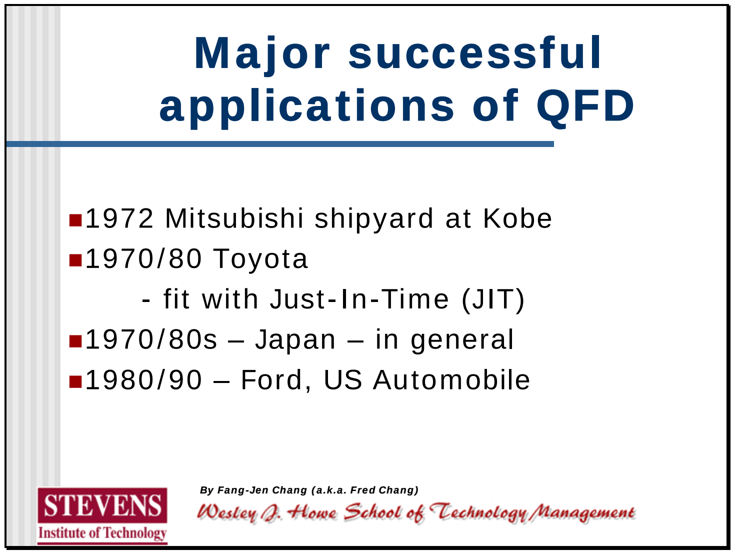
Slide 3



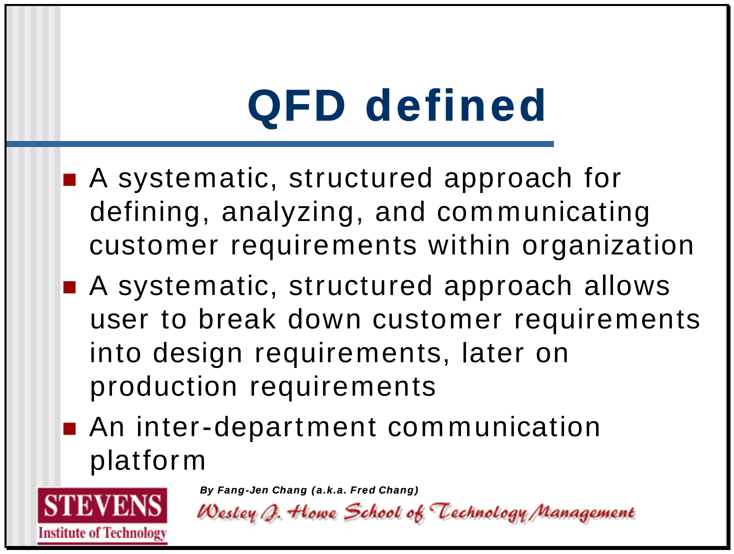
One of the major ideas behind QFD is that quality of a product is defined by customer, not by engineers. Engineers deign the product based the the quality defined by customers. QFD is a versatile methodology allowing users to breakdown the quality into design requirements, later on into production process planning.

Slide 4



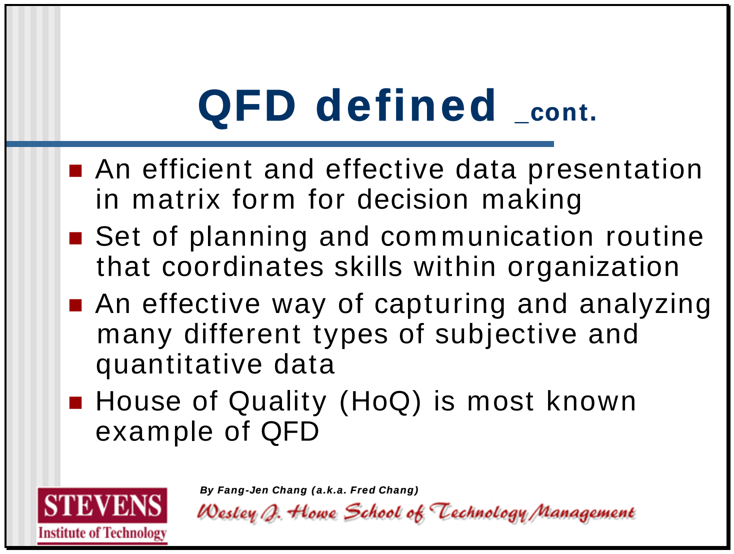
As mentioned in previous slide, QFD was put into successful business practice at Mitsubishi shipyard at Kobe Japan.
In 1970/80, Japanese car company, Toyota, had a successful operation model Just-In-Time. QFD is one of the major method used to achieve JIT.
In 1970/80, Japanese industries implemented QFD to achieve success in product quality and market. Car industry is the most famous case.
1980/90, QFD was adopted by US companies like Ford. The implementation makes the Ford re-gain the market competition with high quality products.

Slide 5



When comes to product design, as proven by practice, quality of product is defined by customers, not engineers. So customer needs should be the design criteria for product. QFD provides a systematic, structured for defining, analyzing, and communicating customer requirements within organization. And allows user to break down customer requirements into design requirements, later on production requirements. From the management view, it is good communication platform for decision-making.

Slide 6



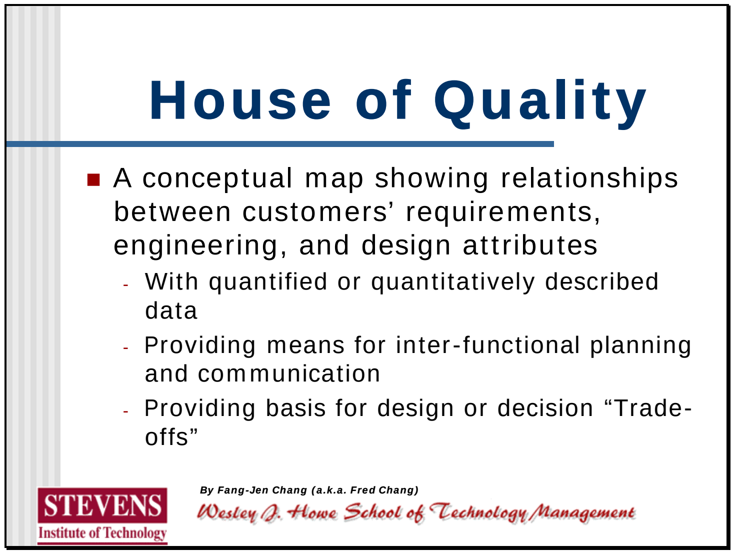
With its matrix form, QFD provides an efficient and effective way of data presentation for decision-making. It enforces two-dimensional thinking.

QFD is also a set of planning and communication routine that coordinates skills within organization. It tells decision makers when to communicate, what to communicate, and what should be involved.

In decision making, it is a challenge when both subjective and quantitative data involved. QFD provides an effective way of capturing and analyzing many types of subjective and quantitative data.

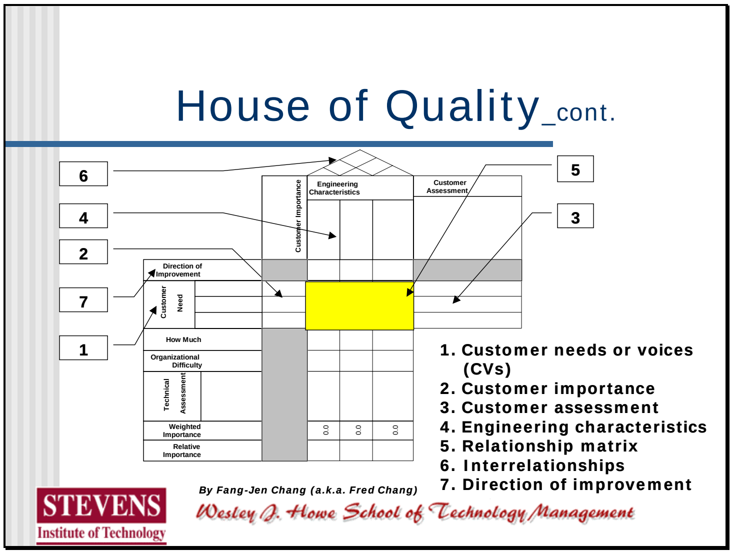
A most well known example of QFD is House of Quality. In next section, House of Quality will be described in detail.

Slide 7



Now let's talk about House of Quality. First, what is House of Quality for? What is its major application? Based on the content House of Quality, it is a conceptual map showing relationships between customers' requirements and engineering/design attributes with quantified or quantitatively described data. QFD not only provides ways for related departments what and when to communicate, it also provide ways for planning for those. With quantified customer requirements and design attributes, QFD provides the basis for decision and design trade-offs.

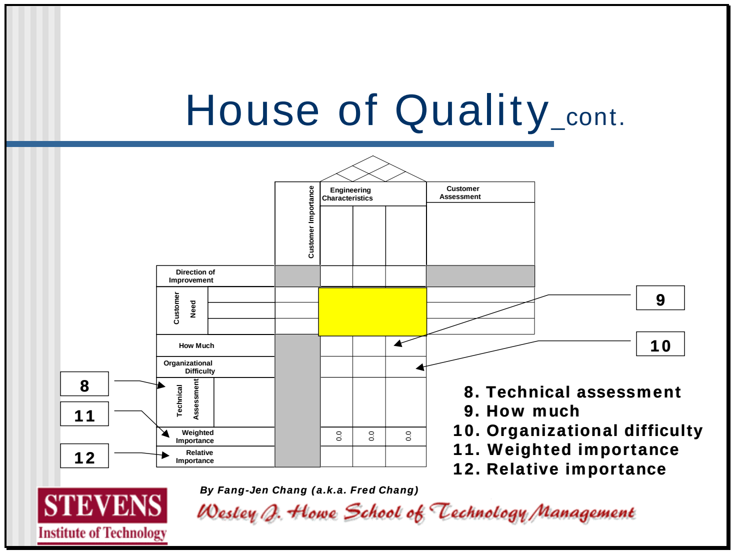
Slide 8



This slide show you blank House of Quality. A House of Quality includes 12 items. Later on, I will explain each section one by one and show you how to create a completed HoQ step by step. Please refer attachment for a completed House of Quality. This slide show item from 1-7.

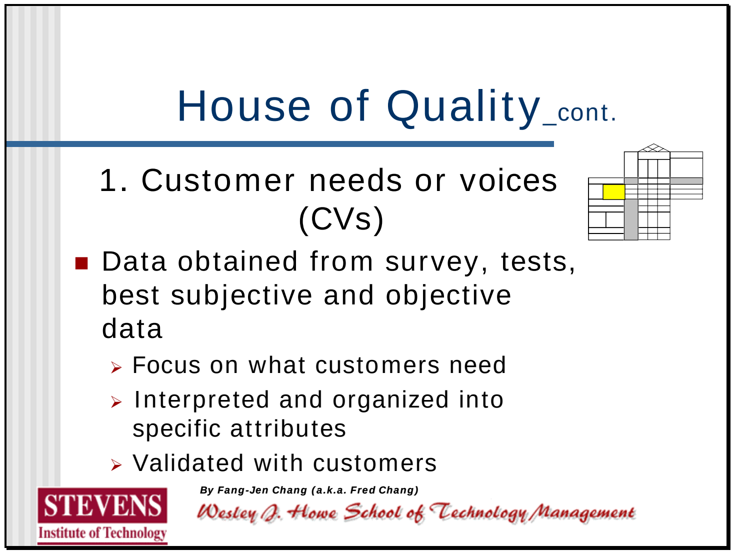
Item 1 is customer needs, or customer voices, section. Also called WHATs
Item 2 is customer importance section
Item 3 is customer assessment section
Item 4 is engineering characteristics section. Also called HOWs.
Item 5 is relationship matrix section
Item 6 is inter-relationship section
Item 7 is direction of improvement

Slide 9



Item 8 is technical assessment
Item 9 is “how much” section
Item 10 is organizational difficulty section
Item 11 is weighted importance
Item 12 is relative importance

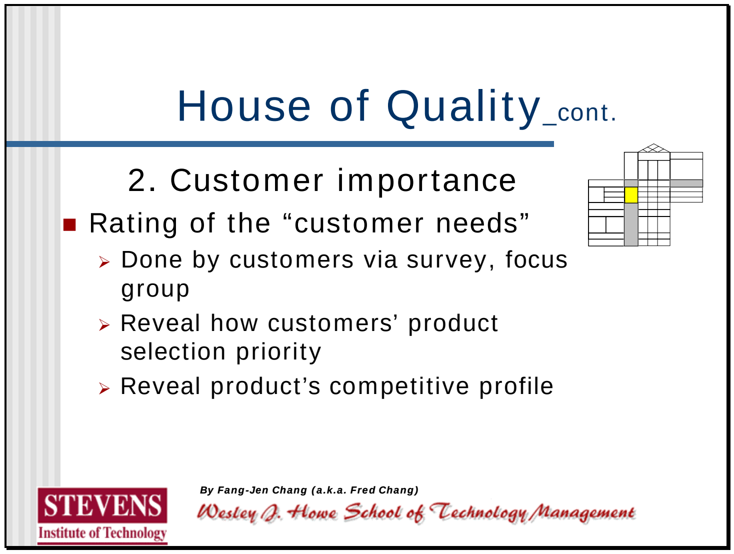
Slide 10



Customer needs, requirements, or voices are how customers profile a product of quality. In short words, they tell you what they want from product and the way they qualify or valuate a good product. Customer needs are sources for product or service improvement. Customer needs could be gathered by survey, interview, focus group, and direct observation etc. Before you do that, you need to identify your customer first. Customer could be internal to your company or external to your company. A customer needs analysis is a plus. Essentially, this could be done by collecting and recording answers to the “Five Ws and the H”.

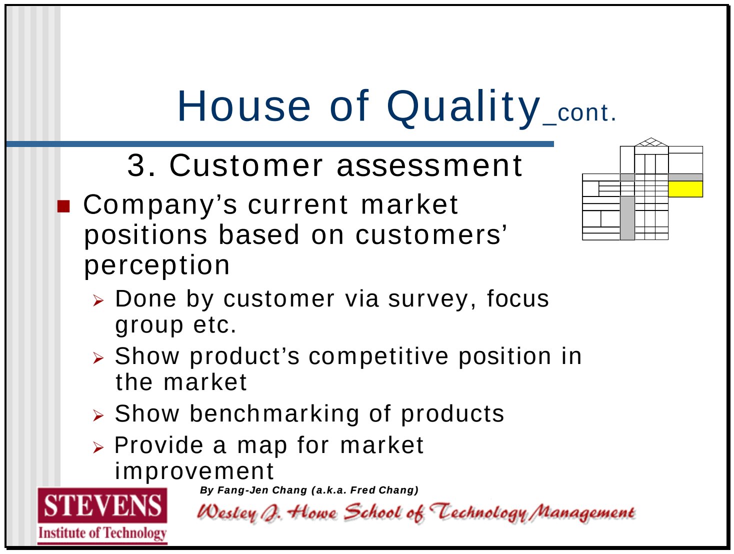
Why? Why do you need or want this product?
What? What will it be used for?
Who? Who use it now and who will use it in the future?
When? When does the customer use it or when will the customer use it?
Where? Where it will be used?
How? How is or will the product be used?
BY doing these, your data and design will 1. more focus on customer needs 2. Be interpreted into specific attributes 3. Validated with customers

Slide 11



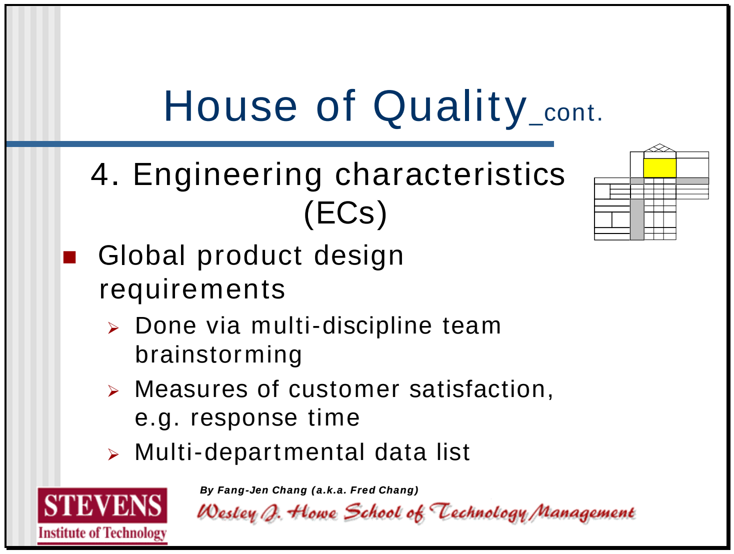
While you collecting customer needs, you also ask them to prioritize their needs. Prioritization could be done using any one of following methods:
Rank each need
Rate each customer need on a scale (1-5, 1-10 etc)
Percentage allocate needs
Use Analytical Hierarchy Analysis (AHP) to do pair-wise comparison within needs
The customer importance shows the customer's product selection priority. They also show the product's competitive profile.

Slide 12



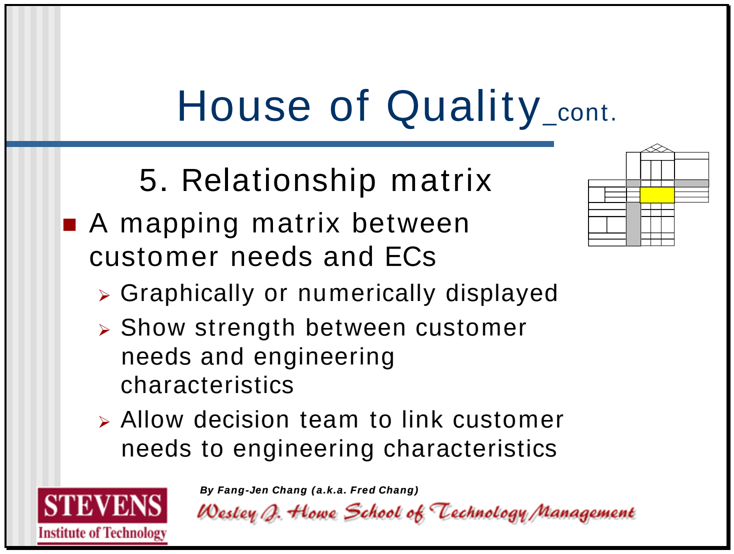
Customer assessment show how competitive your product is.
This could be done in the same survey or focus group by asking customers to rate your product vs. competitor's product for each customer need on a scale (1-5, 1-10 etc)
As a result, customer assessment will give you
Product competitive position in the market
Benchmarking of product
Map of product market improvement

Slide 13



ECs are global design requirements.
After gathering all customer needs for a product, your team has to brainstorm a list of controllable factors or causes which will provide customer needs. This list could cross departments. These factors called engineering characteristics. Guideline it:
Use type of language that your company use
Do not enter solutions! Enter controllable, measurable factors that can be worked on to satisfy the customer need. Enter factors that are “global” in nature (do not imply any specific design intent)
Do not enter too much ECs for each CV. Try to keep the ratio of EC to CV in the range of 1-1.5
Try to draft ECs that can be measured by calculation or simulation. This eliminates the need to create prototypes or samples.

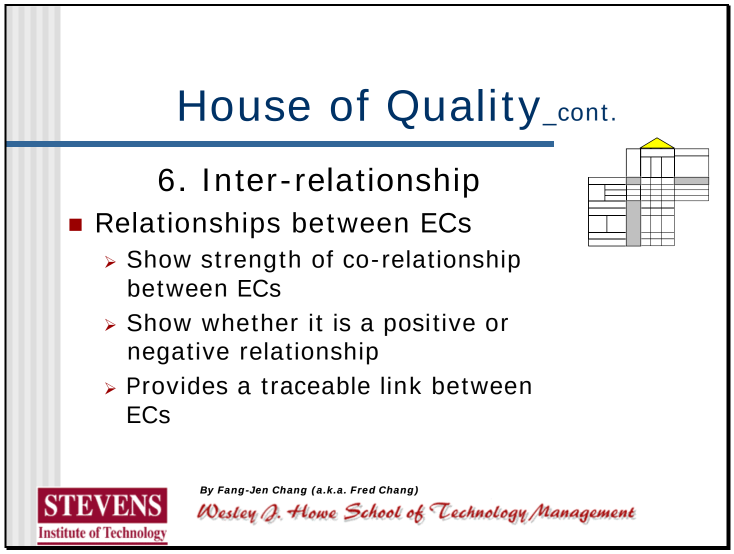
Slide 14



The relationship matrix show numerically, with number, or graphically, with symbol, how strong each EC to each CV. For some people they are used to use verbal values like strong, medium or weak to express the strength of relationship between two objects. And each verbal value will be presented with a symbol. For quantifying, each symbol will have a numerical value. Others like to use numerical value like 3, 5, or 9 etc.

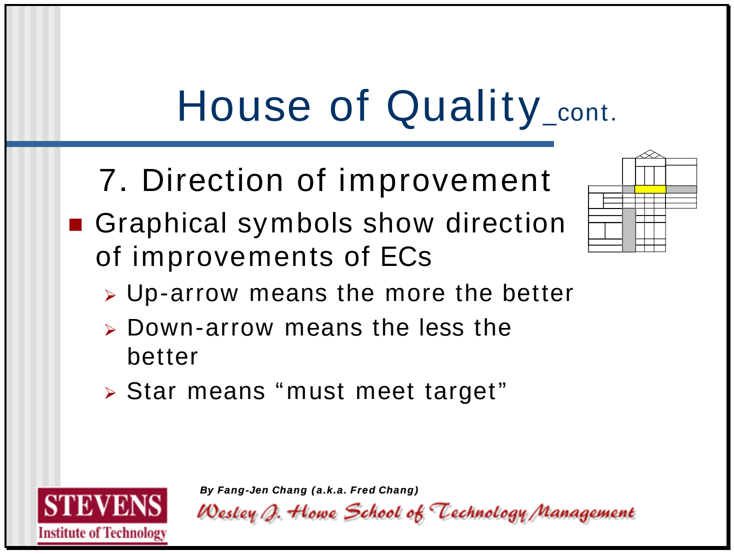
In this way, decision team could trace each CV into related ECs. Mathematically, it means, e.g. , CV1 is a function of EC1, EC2, and EC5.

Slide 15



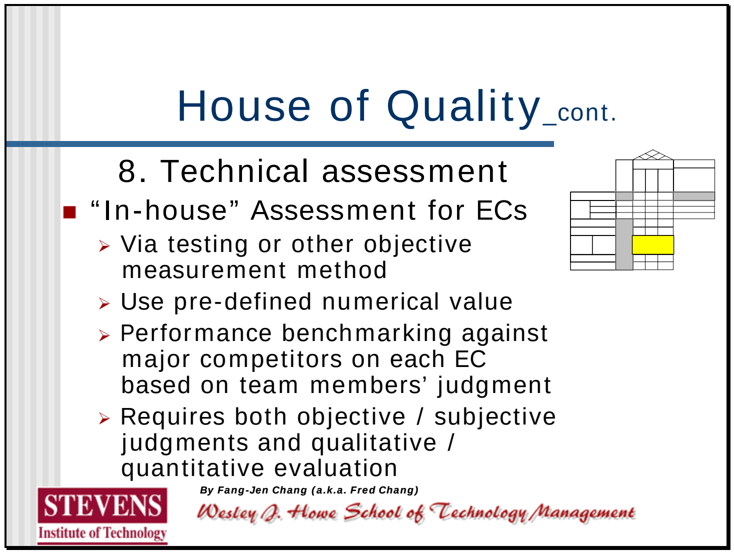
The inter-relationship shows how strong the co-relationship between two ECs. It also show the relationship is positive or negative.

Slide 16



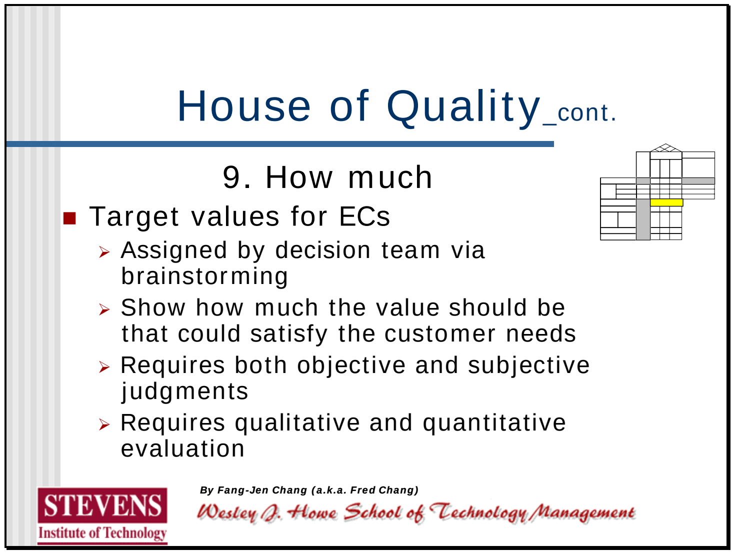
The direction of improvement is for each EC. The nature of an EC could be the more the better. Which means the more EC is the stronger its character.

Slide 17



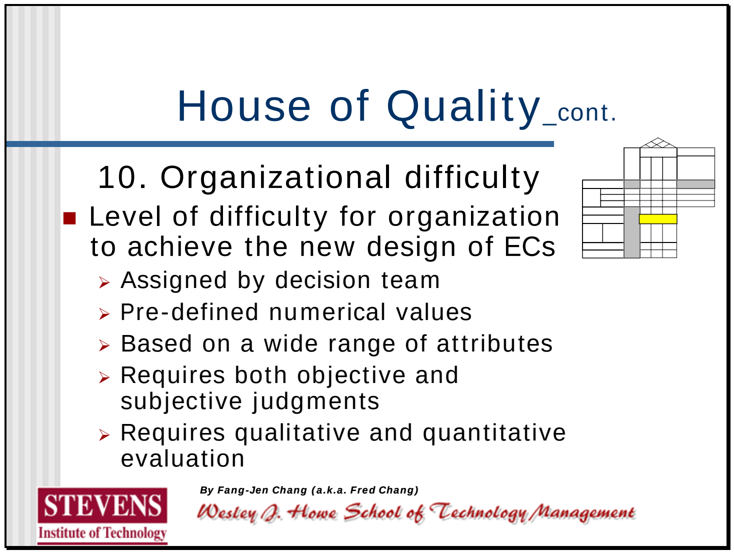
Technical assessment is an internal performance rating using objective testing methods. You test your product and major competitors' product with ECs one by one. The test requires objective and subjective judgment, also the quantitative and qualitative evaluation. The result is product benchmarking within products on each EC.

Slide 18



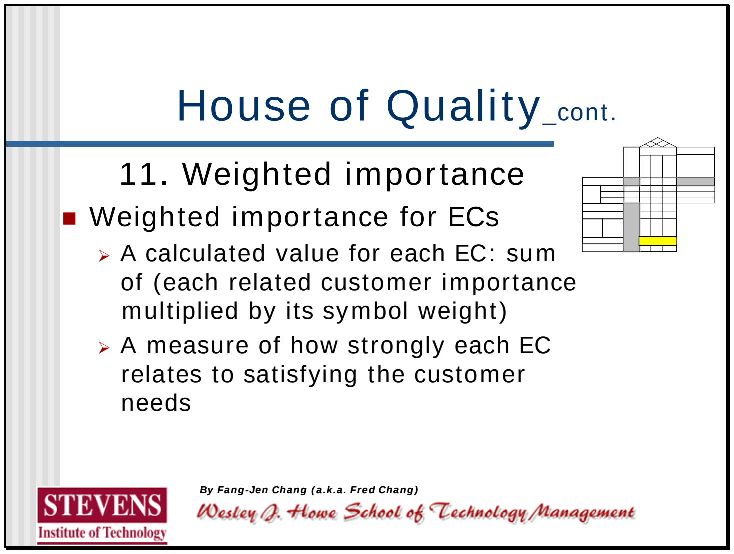
How much means how much the performance targets are. It could be an objective number based on research or subjective number based on your team's judgments. It was done via team brainstorming. These value show how much is enough to satisfy customer. Your team should considers competitive performance position and company performance.

Slide 19



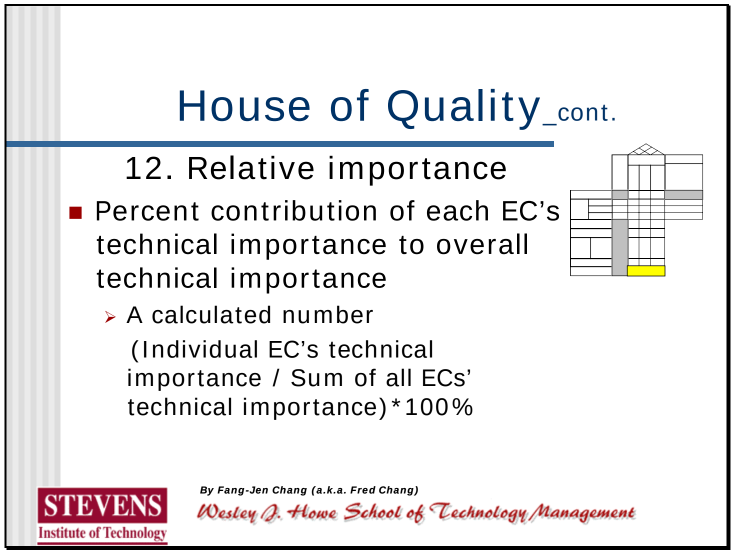
Organizational difficulty means level of difficulty for your company to achieve target EC value. Your team has to assign the difficulty level for each EC's target value. User better uses a user predefined value. The evaluation requires objective and subjective judgments, also qualitative and quantitative evaluation.

Slide 20



Weighted importance shows how important an EC is to satisfy customer needs. It is the sum of production of each related customer importance multiplied by the weight of symbol assigned in the related cell in the matrix.

Slide 21



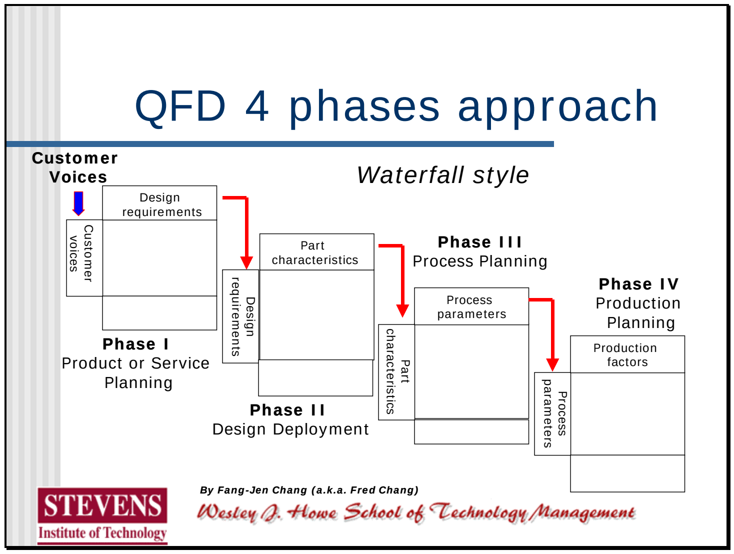
Relative importance is each EC's weighted importance in percentage.

User can sort the EC by weight. It will gives user the priority of EC satisfying customer needs.

This section show you what is HoQ, the usage of HoQ data, and how to process it.

In next section, I will describe the QFD 4 phase approach. The HOWs-WHATs relationship meaning of data in each phase is similar to HoQ. With the same process in phase 1-HoQ, user could translate CVs all the way down to production planning.

Slide 22



The HOWs in previous phase were brought into as WHATs in current phase. Process in all phase is similar to as described in previous section.

Phase I – Product or service planning: House of Quality

This phase is described in detail in previous section.

Phase II – Design deployment

The purpose of this phase is to establish the optimum materials and design. Key outcomes are: 1. Identification of the best design concept. 2. Determination of critical parts. 3. Determination of critical part characteristics. 4. Determination of items for future development.

Phase III – Process planning

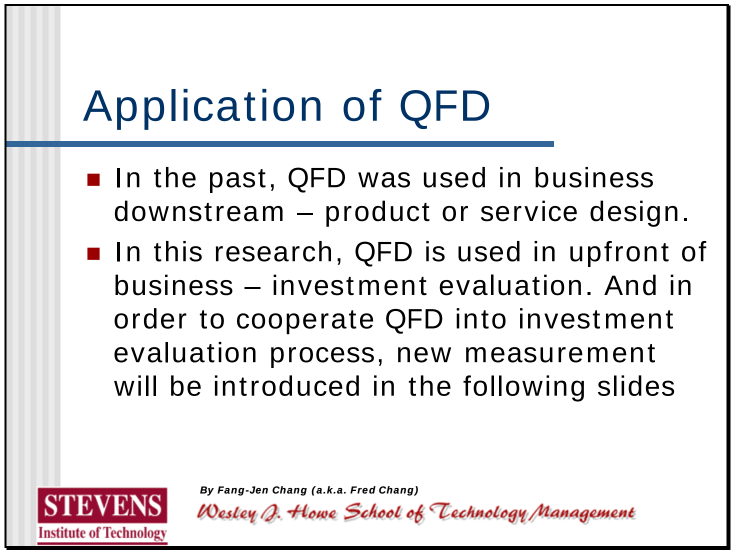
Phase III is used to establish the optimum process setup to manufacture the design determined in phase II. Key outcomes are: 1. Determination of best process/design combination. 2. Determination of the critical process parameters. 3. Establishment of process parameter target values. 4. Determination of items for further development.

Phase IV – Production planning

Phase IV is used to establish the systems that need to be implemented to support the processes selected in phase III. Key output is: evaluation of process operations for achievability.

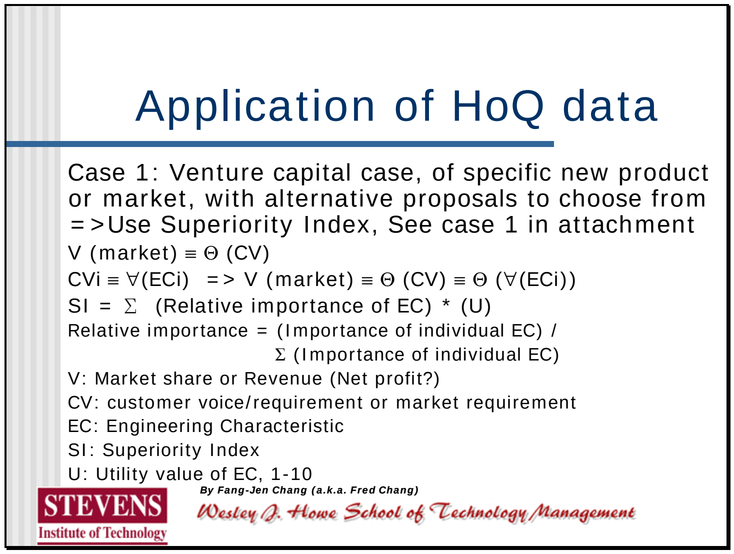
For more information, please refer QFD Designer by QualSoft LLC.
http://www.qualisoft.com

Slide 23



In the past, QFD was major used in product or service design. Later on in 1990's, many companies use QFD to deploy company's strategy etc.
In this research, author will show you that QFD could be used as a tool to assist decision makers make better decision in multi-element decision making process.
In order to implement QFD in investment evaluation process, in this research, 3 index was defined for 3 different cases. The next few slides will show you how they are defined.

Slide 24



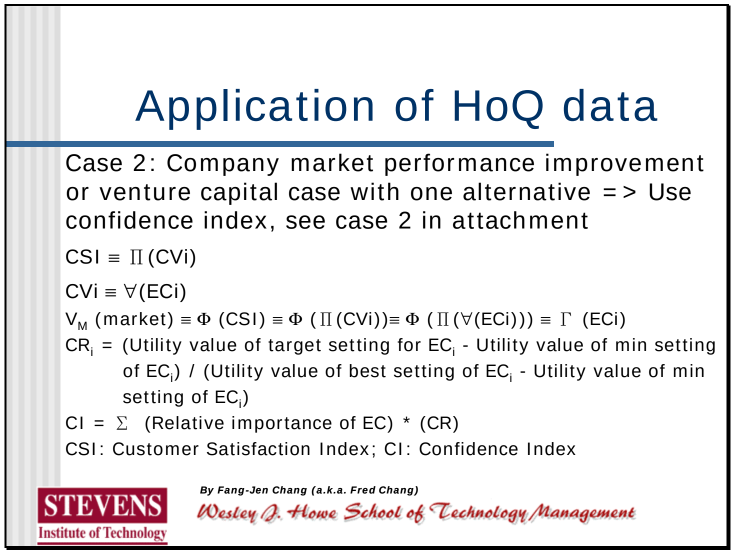
If it is venture capital case, of specific product or market, with alternative proposals to choose from, use Superior Index for final decision. Superior Index is individual relative importance of each EC multiplied by utility value of EC. Then sum them up.

V (market) ≡ (CV)
CVi ≡ (ECi)

where V: Market share or Revenue (Net profit?)
CV: customer voice/requirement or market requirement
EC: Engineering Characteristic
V (market) ≡ (CV)
≡ ((ECi))
≡ (ECi)

SI = Σ (Relative importance of EC) * (Utility value of EC)
SI: Superior Index
Relative importance = (Importance of individual EC) / Σ (Importance of individual EC)
The final decision will be based on Superior Index. Alternative with the highest Superior Index wins.
Utility value of EC is based on the evaluation according to each alternative's performance of specific EC.
The utility value of each EC of individual company is assigned with utility function, scaling method, or AHP.

Slide 25



If it is for company market performance improvement or venture capital case with one alternative, then:

CSI ≡ Π(CVi)

Where CSI: Customer Satisfaction Index
CV: customer voice/requirement or market requirement
EC: Engineering Characteristic

CVi ≡ ∀(ECi)

V (market) ≡ Φ(CSI) V: Market share or Revenue (Net profit?)

⇒ V ≡ Φ(Π(CVi))

⇒ V ≡ Φ(Π((ECi)))

⇒ V ≡ Γ(ECi)

V_M (market) ≡ Φ_B (CV)
≡ Φ_B ((ECi))
≡ Γ_B (ECi)

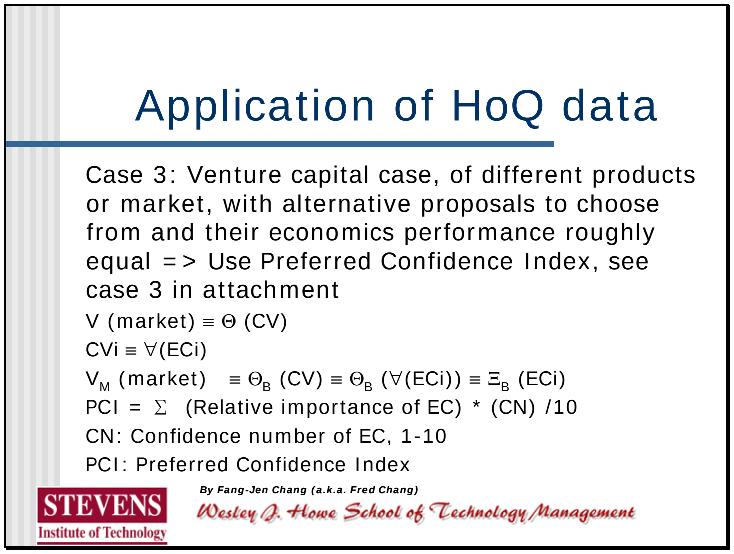
V_M: Target market share could be achieved with **minimum** setting of ECs.
Note: The minimum setting is based on survey or judgment by study team.

CR = (Target setting for EC) / (Medium setting of EC)
where CR: Confidence ratio of EC
Note: Medium setting of EC is the setting of market player with average performance.

CI = Σ (Relative importance of EC) * (CR) CI: Confidence Index

If the CI is less than 1, proposal should be reject. If the CI is great than 1, proposal could be accepted.

Slide 26



If it is venture capital case, of different products or market, with alternative proposals to choose from and their economics and strategy performance roughly equal, use Confidence Index for final decision. Individual relative importance of each EC multiplied critical ration of EC. Then sum them up. Based on the sum, judge which one is better.

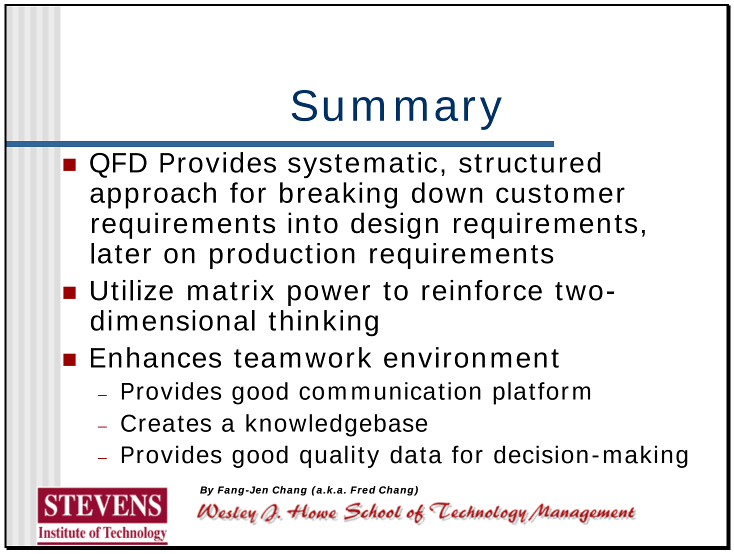
V (market) ≡ Θ (CV)
CVi ≡ ∀ (ECi)
Where V: Market share or Revenue (Net profit?)
CV: customer voice/requirement or market requirement
EC: Engineering Characteristic
Θ : Function of market that relates customer voice to market share.
V_M (market) ≡ Θ_B (CV) ≡ Θ_B ((ECi)) ≡ Θ_B (ECi)

V_M: Target market share could be achieved with **minimum** acceptable setting of ECs.
Note: The minimum setting is based on survey or judgment by study team.

PCI = Σ (Relative importance of EC) * (CV) / 10
PCI: Preferred Confidence Index, Best value is 100
CN: Confidence number. 1-10: 1 means lowest confidence, 10 means highest confidence. Confidence level is the number you assign to each EC based on its setting. If the setting is much better than minimum setting, number "10" will be assigned. When the setting is closer to minimum setting, the lower number should be assigned.

Relative importance = (Importance of individual EC) / Σ (Importance of individual EC)
The final decision is based on PCI. Alternative with highest PCI wins.

Slide 27



From previous sections, we can concludes that QFD
Provides a systematic, structured approach for defining, analyzing, and communicating customer needs within organization and then breaking down the customer requirements into design requirements, and later on to production requirements.
Due to its matrix form, it reinforces two-dimensional thinking which other approaches could not.
QFD enhances the teamwork environment by 1. Providing good communication platform. 2. Creating a team based knowledgebase. 3. Providing good quality data for decision-making

Slide 28

The processes in QFD make team to focus on customer requirement and identifying key processes for meeting customer requirements. As a result, enhances customer oriented business improvement.

Presentation Slides of Introduction to ABC

Slide 1

Activity-Based Costing (ABC)

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9/10/02

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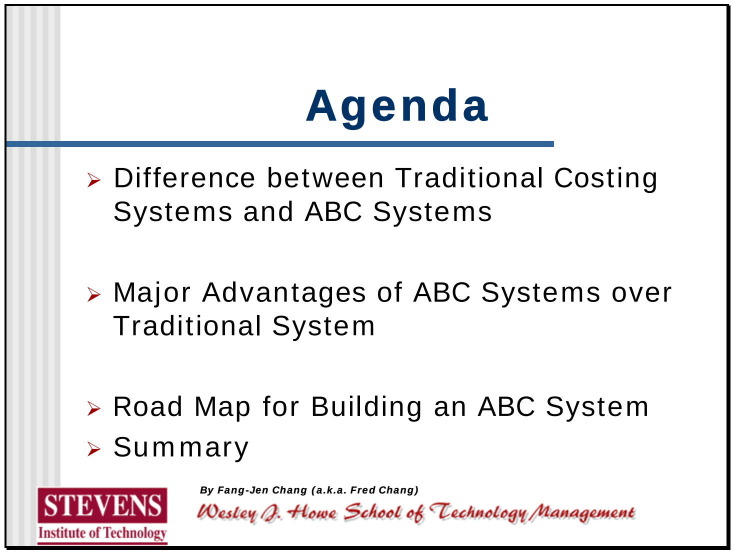
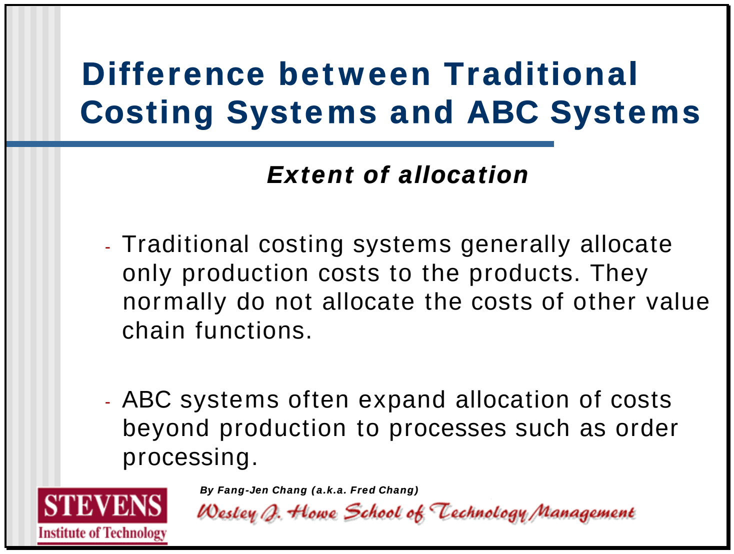
Slide 2


Agenda
Difference between Traditional Costing Systems and ABC Systems
Major Advantages of ABC Systems over Traditional System
Road Map for Building an ABC System
Summary
By Fang-Jen Chang (a.k.a. Fred Chang)
STEVENS
Institute of Technology
Wesley J. Howe School of Technology Management

Slide 3



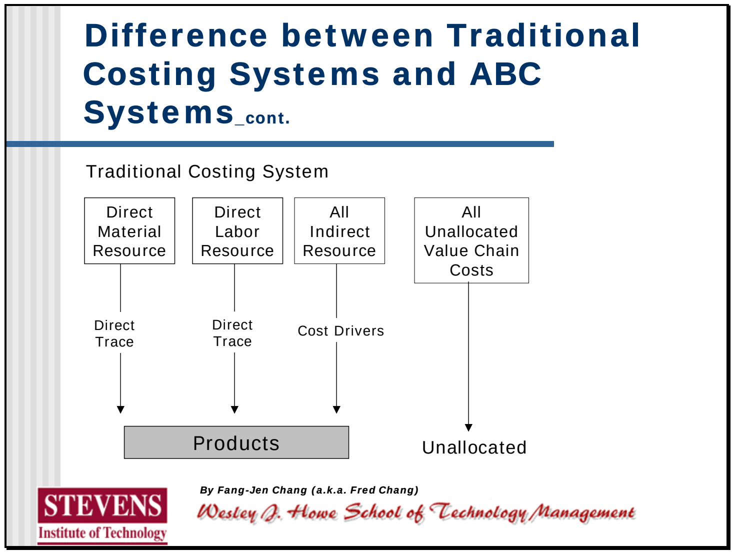
One of the most importance difference is the *extent of allocation.*

Traditional costing systems generally allocate only production costs to the products. They normally do not allocate the costs of other value chain function.

ABC systems often expand allocation of costs beyond production to processes such as order processing. See example in appendix – Illustration of Activity-Based Costing.

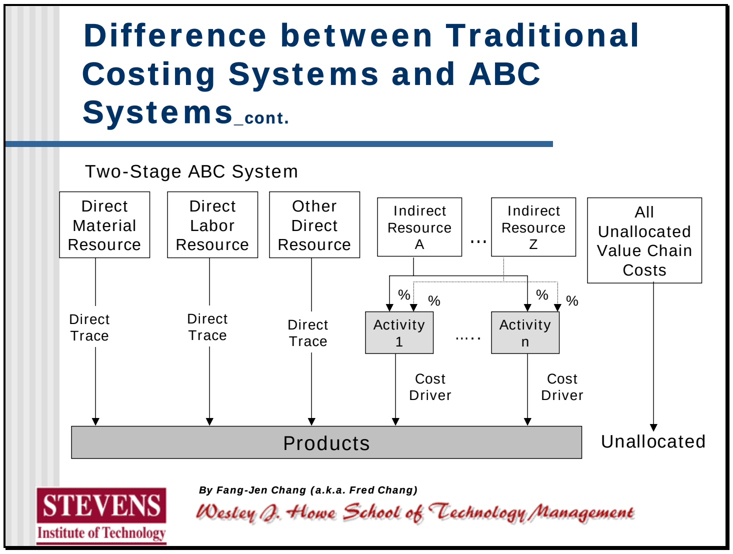
The traditional costing systems use an overhead-allocation approach to assign supporting costs to products. If a company has only one product, the cost distortion is low. If a company has a mix of products, the distortion becomes huge.
ABC systems assign the supporting costs based on how much supporting resources each product consumed. This way, cost distortion is much less.

Slide 4



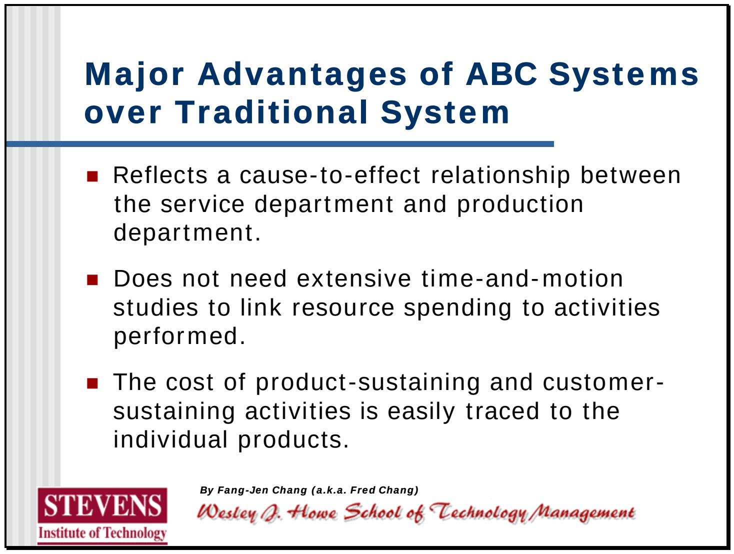
This slide shows graphically the way of cost allocation in traditional costing systems.

Slide 5



This slide shows graphically the way of cost allocation in ABC systems.

Slide 6

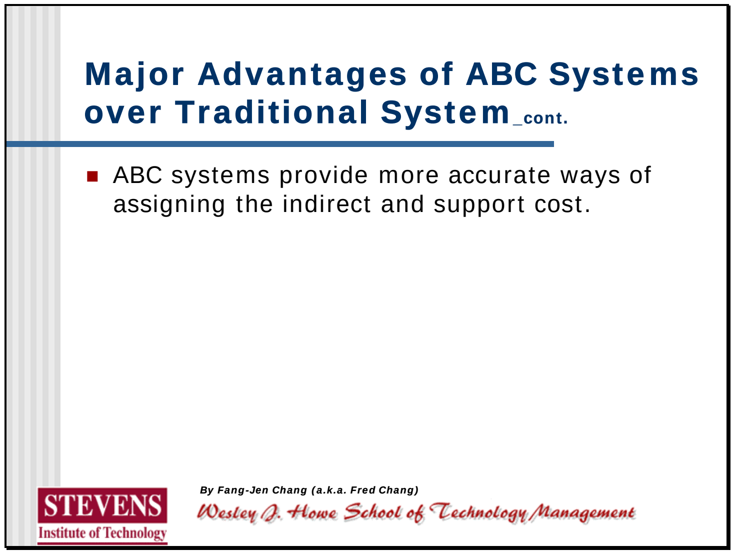


In both traditional costing systems and an ABC system, direct costs are assigned to products in the same way. Indirect costs, such as service department expenses including purchasing, product design, and scheduling are assigned to product in different ways. ABC system provides a mechanism for establishing causal relationships between expenses that must be treated as common or joint in traditional cost systems

ABC data that links resource expenses to activities performed are usually obtained from surveys or interviews. In the surveys or interviews, individuals are asked to estimate the percentage of time, not how much time, they spent on any activity on the activity list for their jobs.

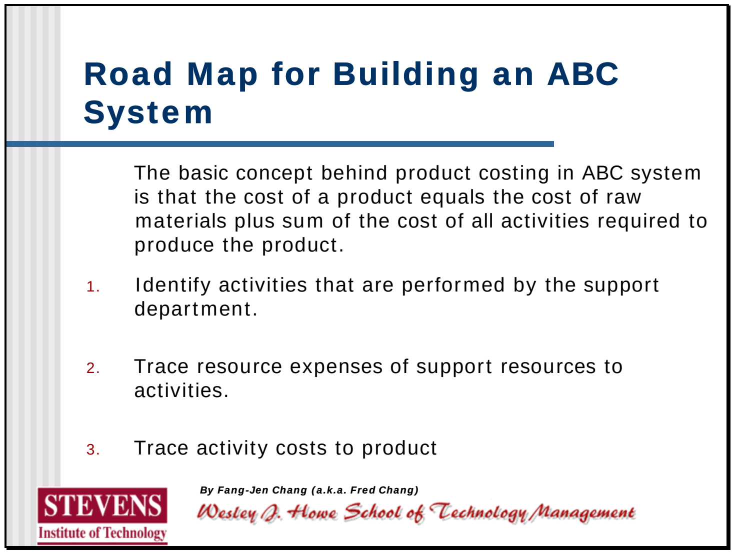
Traditional systems cannot trace product-sustaining and customer-sustaining resources to individual products and customers. In ABC, the cost of product-sustaining and customer-sustaining activities is easily traced to the individual products and services for whom the activities are performed, but the quantity of resources used is independent of the production and sales volumes for the product and customers.

Slide 7



Activity-based costing (ABC) was developed to provide more accurate ways of assigning the cost of indirect and support resources to activities, business processes, products, services, and customers. ABC systems recognize that many organizational resources are required not only for physical production of units of product but to provide a broad array of support activities that enable a variety of products and services to be produced for a diverse of customers

Slide 8



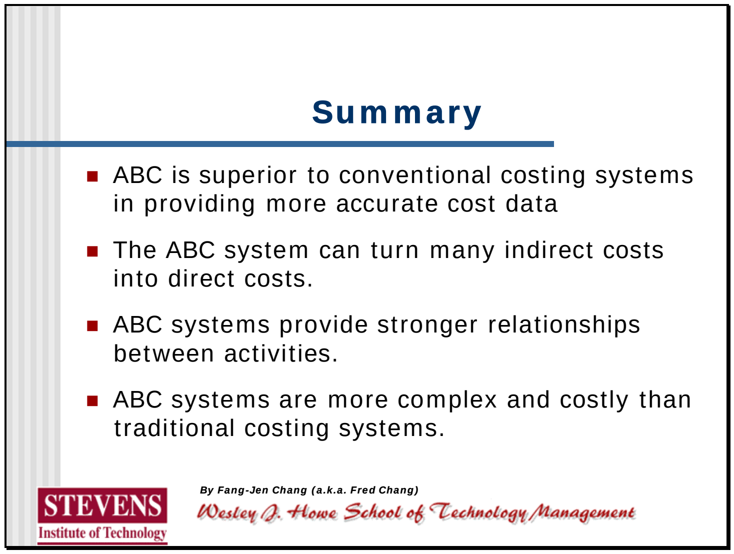
To identify the activities being performed, a survey or interview with the process owner is conducted. The purpose of a survey or interview is to generate a list of activities. Activities performed could be classified into three categories: unit-level activities, batch-level activities, and product-sustaining activities.

The purpose of tracing resource expenses of support expenses to activities is to work out the activity cost drivers. Process owners write down how much time they spend on performing each individual activity. For a resource like space, what percentage of capacity is committed to each individual product is estimated. The activity cost driver is equal to the total resource cost and is divided by the total working hours and then multiplied by the percentage of resource usage.

Activity-cost drivers are used as linkages between activities and products to assign activity costs to products. In this way, costs like batch, customer sustaining, and product sustaining, could be assigned more accurately to individual products.

Steps b & c are named as ABC two stages cost-driver approach.

Slide 9



If the company has only a single product, the cost distortion is not serious. If the company has a mix of products, the cost distortion becomes a serious problem. Traditional costing systems do not attempt to identify, accumulate, or report costs by activities performed, like ABC systems do. So, ABC systems could help managers to allocate these product-supporting costs to products more correctly.

Traditional costing systems allocate only production costs to products. ABC systems allocate the cost beyond production to overall value chain functions, processes such as marketing and customer service, etc.

Based on the relationship between identified activities and resources, managers could trace indirect costs to cost objectives. Managers would have greater confidence in the accuracy of cost information.

The ABC system classifies more costs as direct costs than do traditional costing systems. The more cost classification there is, the more complex the system will be, and the more the system construction cost will be. Although the cost becomes an issue, more and more industries are adopting ABC systems.

Attachment 1

How to evaluate the CRM (Customer Relationship Management) system for the PCB (Printed Circuit Board) fabrication industry using the Chang Model with QFD (Quality Function Deployment) and ABC (Activity Based Costing).

Case description: "**Customer relationship management** is the superset of business models, process methodologies and interactive technologies for achieving and sustaining high levels of retention and referrals within identified categories of valuable and growable customers" - Mei Lin Fung, a contributor at CRMguru.com. CRM has had great success in financial industries like banking, credit card companies etc. Businesses like these have a huge customer base. Most of their customers are end-users. Identifying customer consuming patterns then provides better-fit services becomes a critical competition power. Compared to the banking business, PCB-fabrication industry has much less of a customer base. All customers are not end-users.

Company X, an Original Design and Manufacturing (ODM) type of PCB-fabrication firm, is considering installing a CRM system. Although still in good business shape in the PCB-fabrication industry, the CEO of the company is thinking about how to keep the company in a top position in PCB-fabrication industry. Recently, he had reviewed the PCB industry's business environment. All top players in this field have almost the same production equipment. Every top player had the same problem – production lines are not fulfilled. He is thinking that it is about time to start something new to attract more customers. Recently, he has heard about CRM. Many consultant firms approached his company with CRM projects. He is wondering whether it is worth it to install a CRM system. He asks his management team to evaluate the CRM system.

Company X starts reviewing suggestions and requirements from its customers, and its business and production process. The following is a summery of its customers' major suggestions and requirements[2]:

- More flexible delivery schedule/batch sizes and order sizes acceptation;
- More accurate order status
- Design-consulting service

The director of marketing and the director of production also point out that a customer-data analysis system will be helpful for promoting products.

Questions:

Company level:

1. Could CRM help the company create a customer-oriented overall process?
2. Could CRM help meet customers' major requirements?
3. Is it good time to re-engineer the company's overall process with the CRM project?
4. If CRM keeps its promise, how much can revenue be increased?
5. How much does it really cost? Are there any hidden costs?

Production level:

1. To implement CRM, what should be done in each production related department?
2. How will the implementation impact current production? Product cost? Production process? Revenue generation?

---

[2] These suggestions and requirements are made-up for demo purpose.

Using the General Model ***(See Model description for detail):***

The following demo is for the “Information Collection and Analysis” process in the Chang model without QFD and ABC. Later on, the author will show, using the Chang model with QFD and ABC, how QFD and ABC could be implemented and enhance the evaluation analysis. The Chang model without QFD and ABC is the proposed evaluation model. When put into practice, any single piece of information of new technology, market, or production could be a trigger for the evaluation process.

Process 1. Information Collection and Analysis

- New Technology Information:

  CRM could help retain current customers and find potential customers. (Does CRM hold its ground in the PCB-fabrication industry?)

- Market Information:
  - More flexible delivery schedules and batch sizes
  - More accurate order status

- Operation Information:

  - Assume that there is no on-line production status-inquiry system. Currently, it is done manually.

- Impact study:

  - If the delivery schedules and batch sizes cannot meet certain customers' requirement, company will lose current revenue or lose the chance of generating new revenue.
  - How much will the cost be increased after sizing down the delivery and production batch sizes?
  - Could a smaller delivery-production batch size helps current customers build up Just In Time (JIT) inventory? If yes, how will it impact business?
  - If the company cannot provide more precise order status, some current customers will switch to competitors.

Will CRM be a tactical investment or strategic investment? How much does it cost? Is it a good investment?

Process 2: High-Level Investment-Opportunity Screening

- List of impacts

1. With CRM, a company could have:

   - Better customer-data management;
   - Better efficiency in processing customer requests;

- Better utilization of company resources;
- Better production information; and
- Better company reputation or image

2. Delivery schedules and batch sizes do not meet some customers' requirements:

- X million dollars of revenue will be lost

3. With more flexible delivery schedules and batch sizes:

- Chance of obtaining new customers and Y million dollars of revenue;
- Will help customers and company itself to build Just-in-Time (JIT) inventory systems, which could help to increase the number of major customers; and
- Smaller production and delivery batch sizes will increase the production cost.

4. Not being able to provide more accurate order status:

- Some customers will switch to competitors. Total Z million dollars of revenue will be lost.

- Generating list of possible response

1. Making production and delivery batch sizes flexible;
2. Re-engineering the order-taking and delivery processes;
3. Upgrading the information system; and
4. Doing all the above.

- Study of Economic Benefits

1. Making delivery schedules and batch sizes flexible

If the flexibility meets requirements, how much current or new revenue will be saved or generated? As in the impact study, the company will not lose X million dollars in current revenue. Y million dollars of new revenue will be generated. How much does it cost to do this? Is it worth it?

2. Re-engineering the order-taking and delivery processes

Assuming that the re-engineered processes meet the requirements, how much current revenue/new revenue will be saved/generated? How much does it cost to do this? Is it worth it?

3. Upgrading the information system

Assuming that the upgraded information system meets the requirements, how much new revenue will be generated? How much does it cost to do it? Is it worth it?

4. Doing all the above

Will there be any synergy effect from doing them all?

Note: In the above study, the company can use discounted cash flow to evaluate the individual project.

- Study of strategic benefit

  Have companies' strategies been met? Any benefit? In this case, the strategic benefit could be "better image" – a customer-oriented designed service, more accurate order-status information, etc. The bottom line is not to violate the company's current strategies.

Now, the company should check to what extent CRM could match the results of studies or do even better. And what is the estimated cost for CRM?

- Pass?

The decision on whether the project is a "go" or not will be based on whether CRM could match the result from "Economic Benefit Study" and "Strategy Benefit Study". It is a high-level evaluation. The main purpose of this is to check for any violation against the current strategies or finance policy of the company. Now, it is your decision. Assume the result is "conditional go".

Process 3: Deciding Objectives to be Achieved

- List possible objectives

After the project passes the high-level investment-opportunity screening, the company has to generate a list of possible objectives to be achieved. In this case, these objectives could be:

- Increasing the customer-retention rate;
- Information system being able to trace order status more accurately;
- Being able to respond customer-order request within the required time period based on customers' order size and delivery schedule; and
- Strategic objective: better company image.

- Checking against company's current objectives

Checking whether there are any conflicts with other projects' objectives- if so, how to trade off between them?

- Evaluating objectives

Among all the objectives listed in this project, which ones are practical? What are the target values for them? What are their levels of priority? In this case,

- Increasing the customer-retention rate

  Target rate: 90%.

- The information system being able to trace order status more accurately.

  Target accuracy: 12 hours.

- Being able to response customer-order request within the required time period based on customers' order sizes and delivery schedules.

  Target response time: 4 hours.

- Strategic objective: better image for the company

  Based on the survey, 70 % or more of customers should rate the updated services provided as better than current ones.

- Generating list of qualified objectives and prioritize them

The following are the qualified objectives and their priorities.

1. Being able to respond customer order requests within the required time period based on customers' order sizes and delivery schedules. Target response time: 4 hours.

2. The Information system should be able to trace order status more accurately.

Target accuracy: should be able to match carriers' pick-up schedule[3] within 12 hours.

3. Increasing the customer-retention rate

Target rate: 90%.

4. Strategic objective: better company image.

Based on the survey, 70 % or more customer should rate the updated services provided as better than current ones.

Process 4: Generating of Alternative Action Plans

Alternative 1: Not outsourcing: The Company's MIS department does it without external consultants

Alternative 2: Not outsourcing: The Company's MIS department does it with external consultancies.

Alternative 3: Outsourcing: Hiring a CRM consulting company to do it.

Alternative 4: Outsourcing: Buying a currently existing CRM system from a vender and modifying it if necessary.

[3] If it is for global shipping, then the customary cut-off time should be matched

Alternative 5: Outsourcing: Buy currently existing CRM system from vender and re-engineer the company's current process based the process in CRM system purchased.

Note: The alternatives listed above are high-level solutions. To follow through, a detailed plan for each alternative is required.

Process 5: Selecting the Optimum Alternative

The company decides to use cost, time of completion, knowledge accumulated for company, and company-image improvement as criteria for evaluating alternatives. In this case, AHP seems to be best multi-attribute analysis technique for evaluation.

Process 6: Auditing / Controlling / Measurement System Building

For external measurements:

1. Customer satisfaction rate: What is the current customer-satisfaction rate? What is the customer-satisfaction rate after the implementation of the CRM system?

For internal measurements:

1. Average response time: What is the average response time to customer requests? What is the average response time to customer request after the implementation of the CRM system?

2. The average accuracy of the order status. What is the current average accuracy of the order status? What is the average accuracy of the order status after the implementation of the CRM system?

For the overall performance of the company

1. Customer-retention rate: What is the current customer-retention rate? What is the customer retention rate after the implementation of the CRM system?
2. Newly generated revenue;
3. Revenue contribution per new customer;
4. Number of new customer; and
5. Average order-processing cost per customer

Process 7: Approval and Execution

Using the Model with QFD ***(See Model description for detail):***

The following demo is for the "Information Collection and Analysis" process in the Chang model with QFD.

Process 1. Information Collection and Analysis

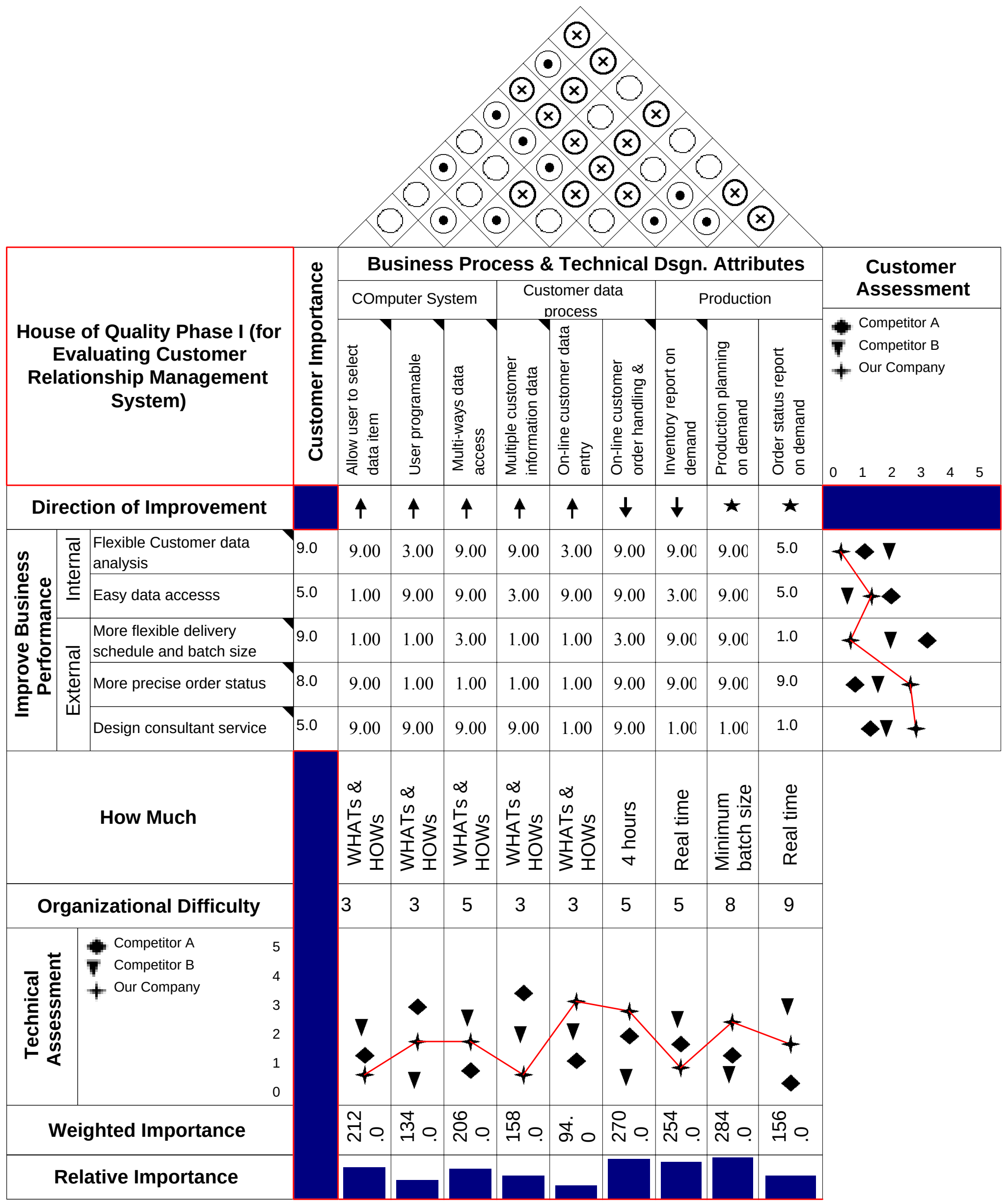
With the customers' voice, apply QFD. Based on the House of Quality (HoQ), are any related processes need to be improved?

- New Technology Information:

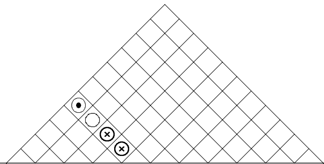
  CRM can help retain current customers and find potential customers. (Is CRM the solution for solving customer requirements?)

- Market Information:
  - More flexible delivery schedules and batch sizes.
  - More accurate order status.

- Operation Information:
  - Assume that there is no on-line production-status inquiry system. Currently, this is done manually.

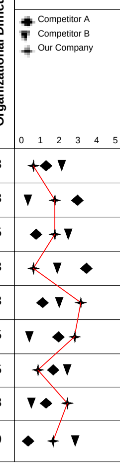


Based on the HoQ, collect any related information that could help to meet customers' requirements.

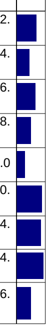


Phase II			Importance	Customer Satisfaction Targets	Drop down User Menu	Pre-defined modules	Web-base database	Company-wise infrastructure	Staffs should be able to use future software	Staffs should know related process	Key staffs should know the meanning of data	Staffs should e able to use available comm. tools	Should have on-site computer workstation	Dynamic production planning system	Dynamic inventory control system	Direction of Improvement	How Much	Organizational Difficulty	Weighted Importance
					Part Characteristics (HOWs)														
					IT. related				Business operation related				Production related						
Business Process & Technical Dsgn. Attributes	COmputer System	Allow user to select data item	212.00	as required	7.00	9.00	3.00	1.00	5.00	7.00	7.00	5.00	1.00	1.00	1.00	↑	WHATs & HOWs	3	212.0
		User programable	134.00	as required	5.00	7.00	3.00	1.00	9.00	5.00	9.00	1.00	1.00	1.00	1.00	↑	WHATs & HOWs	3	134.0
		Multi-ways data access	206.00	as required	1.00	1.00	9.00	9.00	7.00	1.00	3.00	9.00	1.00	1.00	1.00	↑	WHATs & HOWs	5	206.0
	Customer data process	Multiple customer information data menu	158.00	as required	7.00	5.00	1.00	1.00	7.00	7.00	3.00	1.00	5.00	1.00	3.00	↑	WHATs & HOWs	3	158.0
		On-line customer data entry	94.00	as required	5.00	5.00	3.00	5.00	3.00	1.00	1.00	1.00	1.00	1.00	1.00	↑	WHATs & HOWs	3	94.0
		On-line customer order handling & response	270.00	4 hours	5.00	5.00	5.00	3.00	3.00	5.00	3.00	3.00	9.00	9.00	9.00	↓	4 hours	5	270.0
	Production	Inventory report on demand	254.00	Real time	3.00	5.00	1.00	1.00	3.00	5.00	3.00	3.00	5.00	5.00	9.00	↓	Real time	5	254.0
		Production planning on demand	284.00	4 hours	3.00	5.00	1.00	1.00	3.00	5.00	3.00	3.00	3.00	9.00	9.00	★	Minimum batch size	8	284.0
		Order status report on demand	156.00	real time	3.00	5.00	1.00	1.00	3.00	5.00	3.00	3.00	3.00	9.00	1.00	★	Real time	9	156.0
Part Characteristic Values					Survey score	Pass or fail	Yes or No	kilo bit per second	score of test	score of test	score of test.	score of test	Yes or No	time of completion in hours	time of completion in seconds				
Part Capability					3.00	1.00	1.00	56.00	90.00	90.00	90.00	90.00	1.00	4.00	10.00				
Absolute Importance					7368.00	9132.00	5376.00	4332.00	7988.00	8380.00	6768.00	6192.00	6456.00	8464.00	8548.00				
Relative Importance																			

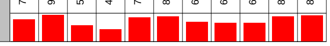
Technical Assessment



Relative Importance



Relative Importance



Part		Phase III	Part Characteristic Values	Importance	Process parameters: software creation – man-power	software creation – team member combination	software creation – time in week	system installation – man-power	system installation – team member combination	system installation – time in week	trainning – staff - time	trainning – trainning type	trainning – trainning material	Part Capability	Absolute Importance
Part	IT. relat	Pre-defined modules	Pass or fail	9132.00	7.00	5.00	7.00	1.00	1.00	1.00	3.00	3.00	5.00	1.00	9132.00
	Business operation	Staffs should be able to use future software	score of test	7988.00	1.00	1.00	1.00	0.00	0.00	0.00	9.00	7.00	7.00	90.00	7988.00
		Staffs should know related process	score of test	8380.00	5.00	5.00	1.00	1.00	1.00	1.00	9.00	7.00	9.00	90.00	8380.00
	Production related	Dynamic production planning system	time of completion in hours	8464.00	9.00	7.00	3.00	5.00	5.00	5.00	5.00	5.00	5.00	4.00	8464.00
		Dynamic inventory control system	time of completion in seconds	8548.00	9.00	7.00	3.00	5.00	5.00	5.00	5.00	5.00	5.00	10.00	8548.00
Process Parameter Values					8	2 - 6	80	5	2-3	3	16	1	1		
Process Capability					12.00		6.00	8.00		2.00	4.00				
Absolute Importance					266920.00	214632.00	131328.00	102572.00	102572.00	102572.00	259768.00	227032.00	262056.00		
Relative Importance															

Process 2: High-Level Investment-Opportunity Screening

- List of impact

1. With CRM, the company could have:

- Better customer-data management;
- Better efficiency inn customer-request processing;
- Better utilization of company's resources;
- Better production information; and
- Better company reputation or image

2. Delivery schedules and batch sizes do not meet some customers' requirements:

   - X million dollars of revenue will be lost;

3. With more flexible delivery schedules and batch sizes:

   - Chance of attracting new customers and Y million dollars in revenue.
   - Will help customers and company itself to build Just-in-Time (JIT) inventory systems, which could help increase the number of major customers.
   - Smaller production and delivery batch sizes will increase the production cost.

4. Not being able to provide more accurate order status:

   - Some customers will switch to competitors. Total Z million dollars in revenue will be lost.

- Generating list of possible responses

1. Making production and delivery batch sizes flexible.
2. Re-engineering the order-taking and delivery processes.
3. Upgrading the information system.
4. Doing all the above.

- Study of Economic Benefits

1. Making delivery schedules and batch sizes flexible

   If the flexibility meets requirements, how much current or new revenue will be saved or generated? As in the impact study, the company will not lose X million dollars in current revenue. Y million dollars in new revenue will be generated. How much does it cost to do this? Is it worth it?

2. Re-engineering the order taking and delivery processes

   Assuming that the re-engineered processes meet the requirements, how much current revenue/new revenue will be saved/generated? How much does it cost to do this? Is it worth it?

3. Upgrading the information system

   Assuming that the upgraded information system meets requirements, how much new revenue will be generated? How much does it cost to do it? Is it worth it?

4. Doing all the above

   Will there be any synergy effect from doing them all?

To judge whether currently the company is capable of doing the above individual response or all of them, look into the QFD phase-I data. Are related departments in your company currently equipped with the required functions? If not, the "hows" in HoQ could be the targets for individual response listed above to create. If your company has some of the required functions, then look into the QFD phase-II data to locate improvement opportunities.

- Study of strategic benefits

  Have the company' strategies been met? Any benefits? In this case, the strategic benefit could be "better image" – a customer-oriented designed service, more accurate order-status information, etc. The bottom line is not to violate the current company's strategies.

Now, the company should check to what extent CRM could match the results of studies or do even better. What is the estimated cost of CRM?

- Pass?

  The decision on whether or not the project is a "go" will be based on whether CRM could match the results from "Economic Benefit Study" and "Strategy Benefit Study". It is a high-level evaluation. The main purpose of this is to check for any violations against the current strategies or finance policies of the company. Now, it is your decision. Assume the result is "conditional go".

Process 3: Deciding Objectives to be Achieved

- Listing the possible objectives

After the project passes the high-level investment-opportunity screening, the company has to generate a list of possible objectives to be achieved. In this case, these objectives could be:

- Increasing the customer-retention rate;
- The information system being able to trace order status more accurately;
- Being able to respond to customer order requests within the required time period based on customers' order size and delivery schedule; and
- Strategic objective: better company image.

- Checking against the Company's Current Objectives

Checking whether there are any conflicts with other projects' objectives- if any, how to trade off between them?

- Evaluating the Objectives

  Among all the listed objectives in this project, which ones are practical? What are the target values for them? What are their priorities? In this case,

  - Increasing the customer-retention rate.

    Target rate: 90%.

  - The information system should be able to trace the order status more accurately.

    Target accuracy: 12 hours.

  - Being able to respond customer order requests within the required time period based on customers' order sizes and delivery schedules.

    Target response time: 4 hours.

  - Strategic objectives: better image for the company

    Based on survey, 70 % or more customers should rate the updated services provided as better than current ones.

- Generating list of qualified objectives and prioritize them

The following is the list of qualified objectives and their priorities.

1. Being able to respond to customer order requests within the required time period based on customers' order sizes and delivery schedules.

Target response time: 4 hours.

2. The information system should be able to trace the order status more accurately.

Target accuracy: should be able to match carriers' pick-up schedule[4] within 12 hours.

3. Increasing the customer-retention rate

Target rate: 90%.

4. Strategic objective: better company image

Based on the survey, 70 % or more customers should rate the updated services provided as better than current ones.

Here, you may have questions about how the target settings of ECs could achieve your objectives? How are you sure about that? The Confidence Index (CI) defined in advanced applications of HoQ will help you to decide whether the settings are good enough. See the simplified example below:

[4] If it is for global shipping, then custom cut-off time should be matched

$\boldsymbol{CSI \equiv \Pi(CVi)}$

where

CSI: Customer Satisfaction Index

CV: customer voice/requirement or market requirement

Π: Function of Customer Satisfaction that relates major CVs to CSI.

$CVi \equiv \forall(ECi)$ where EC: Engineering Characteristic

$V\ (\text{market}) \equiv \Phi\ (CSI)$

⇨ $V \equiv \Phi\ (\Pi(CVi))$

⇨ $V \equiv \Phi\ (\Pi(\forall(ECi)))$

⇨ $V \equiv \Gamma(ECi)$

where V: Market share or Revenue (Net profit?)

Φ: Function of market that relates CSI to market share.

$$V_T\ (\text{market}) \equiv \Phi_B\ (CV)$$

$$\equiv \Phi_B\ (\forall(ECi))$$

$$\equiv \Gamma_B\ (ECi)$$

Γ_B: Function of market that relates ECs to market shares

V_T: The market share could be achieved with the **target** setting of ECs.

Note: The target setting is based on surveys of or judgments of the study team.

CR_i = (Utility value of target setting for EC_i - Utility value of min setting of EC_i) / (Utility value of best setting of EC_i - Utility value of min setting of EC_i)

CR_i: Confidence ratio of EC_i

Note: 1. The best EC setting is the setting of the market player with the best performance.

2. Min. EC setting is the setting of the market player with the least performance.

3. The recommended number range for utility value is 1 – 10.

CI = Σ (Relative importance of EC_i) * (CR_i) where CI: Confidence Index

If your CI is less than that of the current target-market player, the proposal should be rejected. If the CI is greater than that of the current highest market player, the proposal may be accepted.

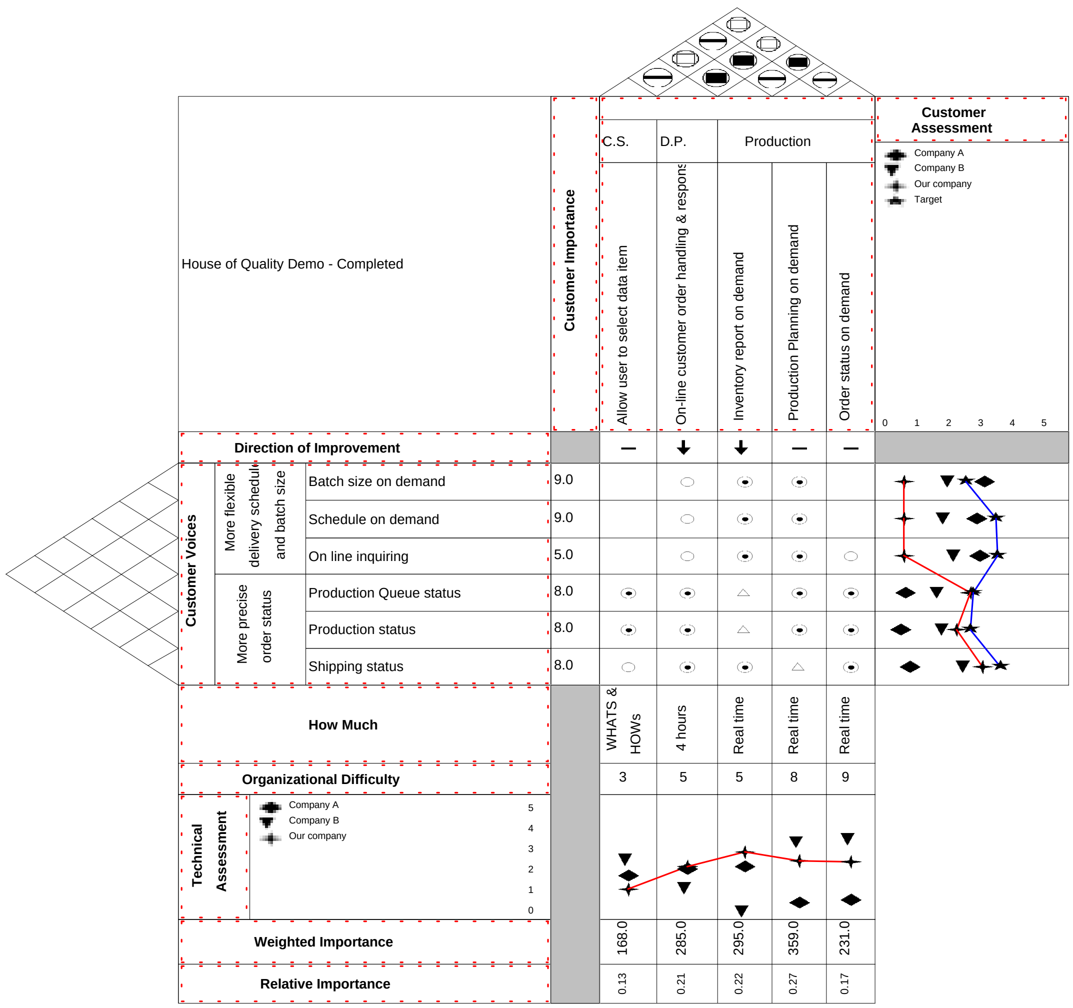
By identifying the key engineering characteristics, the decision-makers could map the ECs into different market strategy by adjusting key ECs.

Example:

Your company is considering investing in a Customer Relationship Management system. Based on the customer survey, the key customer requirements are identified as: A. Flexible delivery schedule and batch size. B. Precise order control. The results of HoQ (see figure, next page) and assessment of companies according to identified ECs are summarized in the following table.

As a result, the confidence index of your target settings is 82.58, which is higher than that of the current best player. The proposal and target setting should be accepted.

	Allow user to select data item	On-line customer order handling & response	Inventory reports on demand	Production planning on demand	Order status on demand	**Confidence Index**
Relative Importance in HoQ	**13**	**21**	**22**	**27**	**17**	
Competitor A	5	8	4	6	7	
Competitor B	3	5	7	4	5	
Competitor C	7	6	6	5	3	
Your company's target setting	7	7	8	5	6	
	CR_i: Confidence ratio of EC_i					
Competitor A	1/2	1	0	1	1	
Competitor B	0	0	1	0	1/2	
Competitor C	1	1/3	2/3	1/2	0	
Your company	1	2/3	4/3	0.5	3/4	
	(Relative importance of EC_i) * (CR_i)					
Competitor A	6.50	21.00	0.00	27.00	17.00	71.50
Competitor B	0.00	0.00	22.00	0.00	8.50	30.50
Competitor C	13.00	7.00	14.67	13.50	0.00	48.17
Your company	13.00	14.00	29.33	13.50	12.75	**82.58**



Process 4: ***Generation of Alternative Action Plans***

Alternative 1: Not outsourcing: The company's MIS department does it without external consultants

Alternative 2: Not outsourcing: The company's MIS department does it with external consultants.

Alternative 3: Outsourcing: Hiring a CRM consulting company to do it.

Alternative 4: Outsourcing: Buying a currently existing CRM system from vendor and modifying it if necessary.

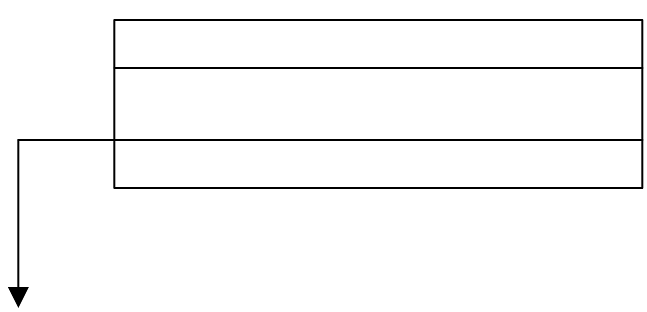
Alternative 5: Outsourcing: Buying a currently existing CRM system from a vendor and re-engineering the company's current process based the process in the CRM system purchased.

Process 5: Selecting the Optimum Alternative

Now, how do you create a list of attributes that will be used to measure the alternatives and make sure the alternatives will result in what you expected? Then how you weigh them? Based on what? Look into the "Hows" in HoQ. In this case, the computer system, customer data process, and production could be your attributes.

The advantage of using the Hows in HoQ is that they are highly related to the predicted cash flow.

The predicted cash-flow diagram:



Process 6: Auditing / Controlling / Measurement System Building

For external measurements:

1. Customer-satisfaction rate: What is the current customer-satisfaction rate? What is the customer satisfaction rate after the implementation of the CRM system?

For internal measurements:

1. Average response time: What is the average response time to customer requests? What is the average response time to customer requests after the implementation of the CRM system?
2. Average accuracy of the order status. What is the current average accuracy of the order status? What is the average accuracy of the order status after the implementation of the CRM system?

For the overall performance of the company

1. Customer-retention rate: What is the current customer-retention rate? What is the customer retention rate after the implementation of the CRM system?
2. Newly generated revenue;
3. Revenue contribution per new customer;
4. Number of new customers; and
5. Average order processing cost per customers.

Process 7: Approval and Execution

Using the Model with ABC ***(See Model description for detail):***

The following demo is for the "Information Collection and Analysis" process in the Chang model with ABC.

Process 1. Information Collection and Analysis

- New Technology Information:

  CRM could help retain current customers and find potential customers. (Does CRM hold its ground in the PCB-fabrication industry?)

- Market Information:
  - More flexible delivery schedules and batch sizes;
  - More accurate order status.

- Operation Information:
  - Assume that there is no on-line production status-inquiry system. Currently, this is done manually.

- Impact study:
  - If the delivery schedule and batch size could not meet certain customers' requirements, the company will lose current revenue or lose the chance of earning new revenue.

- How much will the cost be increased because of sizing down of the delivery and production batch sizes?
- Could smaller delivery-production batch sizes help current customers build up Just-In-Time (JIT) inventory? If yes, how will it impact the business?
- If the company cannot provide more accurate order status, some current customers will switch to competitors.

Will CRM be a tactical or strategic investment? How much does it cost? Is it a good investment?

Process 2: High Level Investment Opportunity Screening

- List of impacts

1. With CRM, the company could have:
    - Better customer-data management;
    - Better efficiency of customer request process;
    - Better utilization of the company's resources;
    - Better production information; and
    - Better company reputation or image.

2. If the delivery schedules and batch sizes do not meet some customers' requirements:

- X million dollars in revenue will be lost.

3. With more flexible delivery schedules and batch sizes:

- There is a chance of attracting new customers and Y million dollars in revenue;
- Will help customers and the company itself to build Just-in-Time (JIT) inventory systems, which could help to increase the number of major customers; and
- Smaller production and delivery batch size will increase the production cost.

4. Not being able to provide more accurate order status:

- Some customers will switch to competitors. A total of Z million dollars in revenue will be lost.

- Generating list of possible responses

1. Making production and delivery batch sizes flexible;
2. Re-engineering the order-taking and delivery processes;
3. Upgrading the information system; and

4. Doing all the above.

- Study of Economic Benefit

In addition to all the processes undertaken in the General model, all possible responses will be studied in term of their impacts on products' unit price via ABC[5].

1. Making delivery schedules and batch sizes flexible

    If the flexibility meets requirements, how much current or new revenue will be saved or generated? As in the impact study, company will not lose X million dollars in current revenue. Y million dollar in new revenue will be generated. How much does it cost to do this? Is it worth it?

2. Re-engineering the order-taking and delivery processes

    Assuming that the re-engineered processes meet requirements, how much current revenue/new revenue will be saved/generated? How much does it cost to do this? Is it worthy to do it?

3. Upgrading the information system

    Assuming that the upgraded information system meets requirements, how much new revenue will be generated? How much does it cost to do it? Is it worth it?

[5] See example in appendix of this attachment

4. Doing all the above

Will there be any synergy effect from doing them all?

Note: In the above study, the company could use discounted cash flow to evaluate the individual project.

- Study of strategic benefits

Have the company's strategies been met? Any benefit? In this case, the strategic benefit could be a "better image" – a customer-oriented designed service, more accurate order-status information, etc. The bottom line is not to violate the company's current strategies.

Now, the company should check to what extent CRM could match the results of studies or do even better. And what is the estimated cost for CRM?

- Pass?

Decision on whether or not the project is a "go" will be based on whether CRM could match the results from the "Study of Economic Benefits" and "Study of Strategy Benefits". It is a high-level evaluation. The main purpose of this is to check for any violation against the current strategies or finance policies of the company. Now, it is your decision. Assume the result is a "conditional go".

Process 3: Deciding Objectives to be Achieved

- Listing the possible objectives

After the project passes the high-level investment-opportunity screening, the company has to generate a list of possible objectives to be achieved. In this case, these objectives could be:

- Increasing the customer-retention rate;
- The information system should be able to trace order status more accurately;
- Being able to respond to customer order requests within the required time period based on customers' order sizes and delivery schedules; and
- Strategic objectives: better company image

- Check against company's current objectives

Checking whether there are any conflicts with other projects' objectives- if any, how to trade off between them?

- Evaluating the objectives

Among all the listed objectives in this project, which ones are practical? And what are the target values for them? What are their levels of priority? In this case,

- Increasing the customer-retention rate

Target rate: 90%.

- The information system should be able to trace order status more accurately.

  Target accuracy: 12 hours.

- Being able to respond to customer order requests within the required time period based on customers' order sizes and delivery schedules.

  Target response time: 4 hours.

- Strategic objective: better image for the company

  Based on the survey, 70 % or more customers should rate the updated services provided as better than current ones.

- Generating a list of qualified objectives and prioritizing them

The following is the list of qualified objectives and their priority levels.

1. Being able to respond to customer order requests within the required time period based on customers' order sizes and delivery schedules.

Target response time: 4 hours.

2. The information system should be able to trace order status more accurately.

Target accuracy: should be able to match carriers' pick-up schedule[6] within 12 hours.

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[6] If it is for global shipping, then custom cut-off time should be matched

3. Increasing the customer-retention rate
Target rate: 90%.

4. Strategic objective: better company image
Based on the survey, 70 % or more customer should rate the updated services provided as better than current ones.

Process 4: Generating of Alternative Action Plans

Alternative 1: Not outsourcing: The company's MIS department does it without external consultants.

Alternative 2: Not outsourcing: The company's MIS department does it with external consultants.

Alternative 3: Outsourcing: Hiring a CRM consulting company to do it.

Alternative 4: Outsourcing: Buying a currently existing CRM system from a vendor and modifying it if necessary.

Alternative 5: Outsourcing: Buying a currently existing CRM system from a vendor and re-engineering the company's current process based the process in the CRM system purchased.

Note: The alternatives listed above are high-level solutions. To follow through, a detailed plan for each alternative is required.

Process 5: Selection of Optimum Alternative

The company decides to use cost, time of completion, knowledge accumulated for company, and company-image improvement as criteria for evaluating alternatives. In this case, AHP seems to be the best multi-attribute analysis technique for evaluation.

Process 6: Auditing / Controlling / Measurement System Building

For external measurements:

1. Customer satisfaction rate: What is the current customer-satisfaction rate? What is the customer-satisfaction rate after the implementation of the CRM system?

For internal measurements:

1. Average response time: What is the average response time to customer requests? What is the average response time to customer requests after the implementation of the CRM system?
2. Average accuracy of order status. What is the current average accuracy of the order status? What is the average accuracy of the order status after the implementation of the CRM system?

For the overall performance of the company:

1. Customer-retention rate: What is the current customer-retention rate? What is the customer-retention rate after the implementation of the CRM system?

2. Newly generated revenue;
3. Revenue contribution per new customer;
4. Number of new customers; and
5. Average order processing cost per customer.

Process 7: Approval and Execution

Using the Model with QFD and ABC ***(See Model description for detail):***

The following demo is for the "Information Collection and Analysis" process in the Chang model with QFD and ABC .

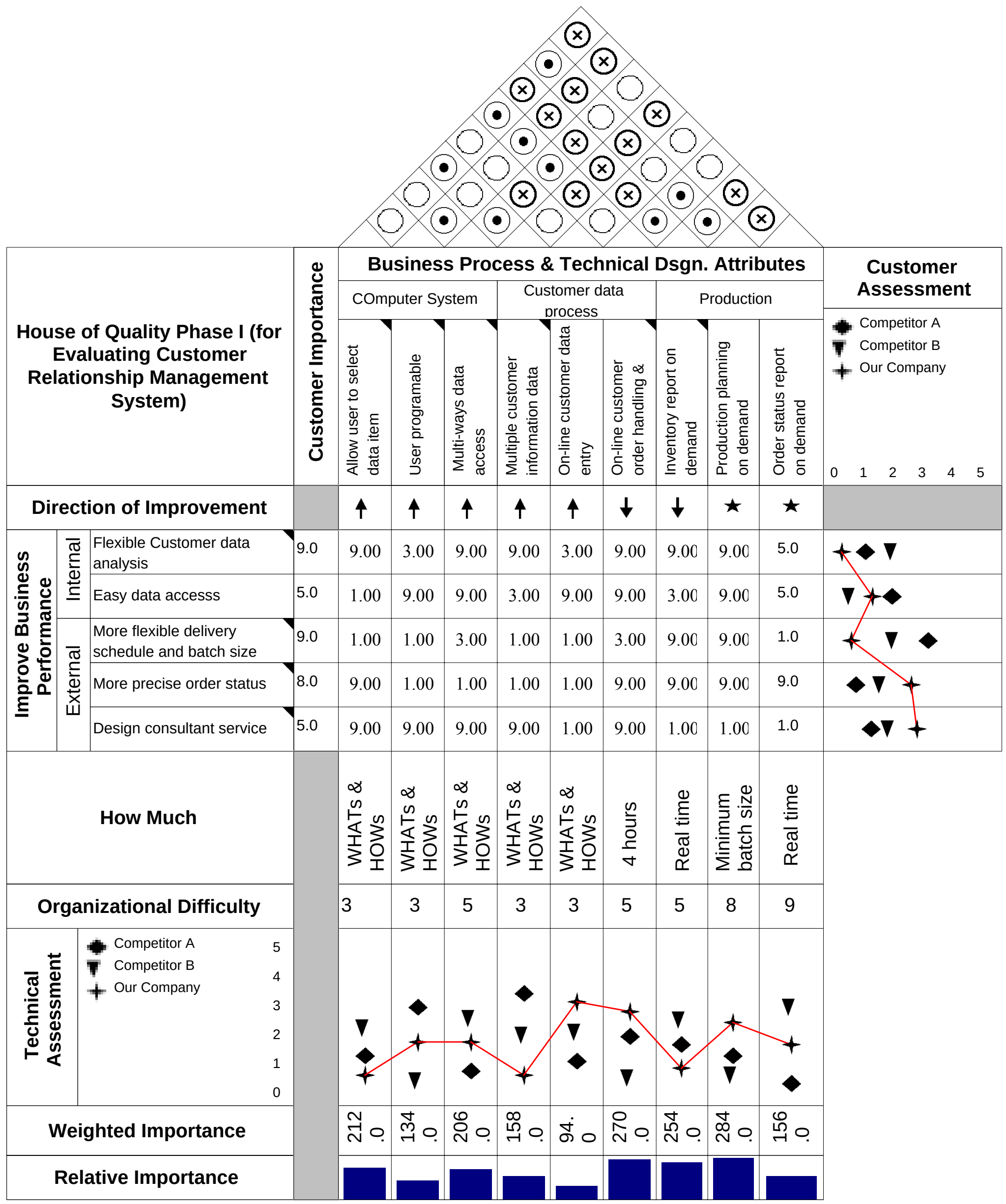
Process 1. Information Collection and Analysis

- New Technology Information:

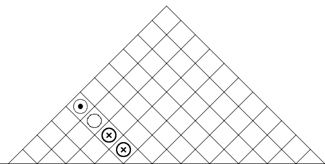
  With the customers' voice, apply QFD. Based on the House of Quality (HoQ), do any related processes need to be improved? CRM could help retain current customers and find potential customers. (Is CRM the solution for meeting the customer requirements?)

- Market Information:
  - More flexible delivery schedules and batch sizes;
  - More precise order status.

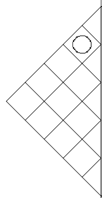
- Operation Information:
  - Assume that there is no on-line production status inquiring system. Currently, this is done manually.



Based on the HoQ, collect any related information that could help to meet the customers’ requirements.



Business Process & Technical Dsgn. Attributes		Phase II	Importance	Customer Satisfaction Targets	Part Characteristics (HOWs): IT. related – Drop down User Menu	IT. related – Pre-defined modules	IT. related – Web-base database	IT. related – Company-wise infrastructure	Business operation related – Staffs should be able to use future software	Business operation related – Staffs should know related process	Business operation related – Key staffs should know the meanning of data	Business operation related – Staffs should e able to use available comm. tools	Production related – Should have on-site computer workstation	Production related – Dynamic production planning system	Production related – Dynamic inventory control system	Direction of Improvement	How Much	Organizational Difficulty	Technical Assessment (Competitor A, Competitor B, Our Company; 0 1 2 3 4 5)	Weighted Importance	Relative Importance
Business Process & Technical Dsgn. Attributes	COmputer System	Allow user to select data item	212.00	as required	7.00	9.00	3.00	1.00	5.00	7.00	7.00	5.00	1.00	1.00	1.00	↑	WHATs & HOWs	3		212.0	
		User programable	134.00	as required	5.00	7.00	3.00	1.00	9.00	5.00	9.00	1.00	1.00	1.00	1.00	↑	WHATs & HOWs	3		134.0	
		Multi-ways data access	206.00	as required	1.00	1.00	9.00	9.00	7.00	1.00	3.00	9.00	1.00	1.00	1.00	↑	WHATs & HOWs	5		206.0	
	Customer data process	Multiple customer information data menu	158.00	as required	7.00	5.00	1.00	1.00	7.00	7.00	3.00	1.00	5.00	1.00	3.00	↑	WHATs & HOWs	3		158.0	
		On-line customer data entry	94.00	as required	5.00	5.00	3.00	5.00	3.00	1.00	1.00	1.00	1.00	1.00	1.00	↑	WHATs & HOWs	3		94.0	
		On-line customer order handling & response	270.00	4 hours	5.00	5.00	5.00	3.00	3.00	5.00	3.00	3.00	9.00	9.00	9.00	↓	4 hours	5		270.0	
	Production	Inventory report on demand	254.00	Real time	3.00	5.00	1.00	1.00	3.00	5.00	3.00	3.00	5.00	5.00	9.00	↓	Real time	5		254.0	
		Production planning on demand	284.00	4 hours	3.00	5.00	1.00	1.00	3.00	5.00	3.00	3.00	3.00	9.00	9.00	★	Minimum batch size	8		284.0	
		Order status report on demand	156.00	real time	3.00	5.00	1.00	1.00	3.00	5.00	3.00	3.00	3.00	9.00	1.00	★	Real time	9		156.0	
Part Characteristic Values					Survey score	Pass or fail	Yes or No	kilo bit per second	score of test	score of test	score of test.	score of test	Yes or No	time of completion in hours	time of completion in seconds						
Part Capability					3.00	1.00	1.00	56.00	90.00	90.00	90.00	90.00	1.00	4.00	10.00						
Absolute Importance					7368.00	9132.00	5376.00	4332.00	7988.00	8380.00	6768.00	6192.00	6456.00	8464.00	8548.00						
Relative Importance																					



Phase III			Part Characteristic Values	Importance	Process parameters: software creation			Process parameters: system installation			Process parameters: trainning			Part Capability	Absolute Importance
					man-power	team member combination	time in week	man-power	team member combination	time in week	staff - time	trainning type	trainning material		
Part	IT. relat	Pre-defined modules	Pass or fail	9132.00	7.00	5.00	7.00	1.00	1.00	1.00	3.00	3.00	5.00	1.00	9132.00
	Business operation	Staffs should be able to use future software	score of test	7988.00	1.00	1.00	1.00	0.00	0.00	0.00	9.00	7.00	7.00	90.00	7988.00
		Staffs should know related process	score of test	8380.00	5.00	5.00	1.00	1.00	1.00	1.00	9.00	7.00	9.00	90.00	8380.00
	Production related	Dynamic production planning system	time of completion in hours	8464.00	9.00	7.00	3.00	5.00	5.00	5.00	5.00	5.00	5.00	4.00	8464.00
		Dynamic inventory control system	time of completion in seconds	8548.00	9.00	7.00	3.00	5.00	5.00	5.00	5.00	5.00	5.00	10.00	8548.00
Process Parameter Values					8	2 - 6	80	5	2-3	3	16	1	1		
Process Capability					12.00		6.00	8.00		2.00	4.00				
Absolute Importance					266920.00	214632.00	131328.00	102572.00	102572.00	102572.00	259768.00	227032.00	262056.00		
Relative Importance															

Process 2: High-Level Investment-Opportunity Screening

- List of impacts

1. With CRM, the company could have:

- Better customer-data management;
- Better efficiency in customer-request process;
- Better utilization of the company's resources;
- Better production information; and
- Better company reputation or image.

2. If the delivery schedule and batch size does not meet some customers' requirements:

- X million dollars in revenue will be lost.

3. With more flexible delivery schedules and batch sizes:

- There is a chance of attracting new customers and Y million dollars of revenue;
- Will help customers and the company itself to build Just-in-Time (JIT) inventory systems, which could help increase the number of major customers.
- Smaller production and delivery batch sizes will increase the production cost.

4. Not being able to provide more accurate order status:

- Some customers will switch to competitors. Total Z million dollars in revenue will be lost.

- Generating list of possible responses

1. Making the production and delivery batch sizes flexible;
2. Re-engineering the order-taking and delivery processes;
3. Upgrading the information system; and
4. Doing all the above.

- Study of Economic Benefits

In addition to all processes undertaken in the Chang model with QFD, all possible response actions will be studied in terms of their impact on the products' unit price.

1. Making delivery schedules and batch sizes flexible

   If the flexibility meets requirements, how much current or new revenue will be saved or generated? As in the impact study, a company will not lose X million dollars in current revenue. Y million dollars in new revenue will be generated. How much does it cost to do this? Is it worth it?

2. Re-engineering the order-taking and delivery processes

   Assuming that the re-engineered processes meet the requirements, how much current revenue/new revenue will be saved/generated? How much does it cost to do this? Is it worth it?

3. Upgrading the information system

   Assuming that the upgraded information system meets requirements, how much new revenue will be generated? How much does it cost to do it? Is it worth it?

4. Doing all the above

   Will there be any synergy effect from doing them all?

- Study of strategic benefit

Have the company's strategies been met? Any benefits? In this case, the strategic benefit could be a "better image" – a customer-oriented designed service, more accurate order-status information, etc. The bottom line is not to violate the company's current strategies.

Now, the company should check to what extent CRM could match the results of studies or do even better. What is the estimated cost for CRM?

- Pass?

The decision on whether or not the project is a "go" will be based on whether CRM could match the result from "Study of Economic Benefits" and "Study of Strategy Benefits". It is a high-level evaluation. The main purpose of this is to check for any violation against the current strategies or finance policies of the company. Now, it is your decision. Assume the result is a "conditional go".

Process 3: Decide what objectives to be achieved

- Listing the possible objectives

After the project passes the high-level investment-opportunity screening, the company has to generate a list of possible objectives to be achieved. In this case, these objectives could be:

- Increasing the customer-retention rate;

- The information system should be able to trace order status more accurately;
- Being able to respond to customer order requests within the required time period based on customers' order sizes and delivery schedules; and
- Strategic objective: better company image

- Checking against company's current objectives

Checking whether there are any conflicts with other projects' objectives- if yes, how to trade off between them?

- Evaluating objectives

Among all the listed objectives in this project, which ones are practical? What are the target values for them? What are their priorities level? In this case,

- Increasing the customer-retention rate

  Target rate: 90%.
- The information system should be able to trace order status more accurately.

  Target accuracy: 12 hours.

- Being able to respond to customer order requests within the required time period based on customers' order sizes and delivery schedules.

  Target response time: 4 hours.

- Strategic objective: better image for the company

  Based on the surveys, 70 % or more customer should rate the updated services provided as better than the current ones.

- Generating a list of qualified objectives and prioritizing them

The following are the list of qualified objectives and their priority.

1. Being able to respond to customer order requests within the required time period based on customers' order sizes and delivery schedules. Target response time: 4 hours.
2. The information system should be able to trace order status more accurately.

   Target accuracy: should be able to match carriers' pick-up schedule[7] within 12 hours.
3. Increasing the customer-retention rate

[7] If it is for global shipping, then custom cut-off time should be matched

Target rate: 90%.

4. Strategic objective: better company image

   Based on the surveys, 70 % or more customer should rate the updated services provided as better than the current ones.

Process 4: Generating of Alternative Action Plans

Alternative 1: Not outsourcing: The company's MIS department does it without external consultants.

Alternative 2: Not outsourcing: The company's MIS department does it with external consultants.

Alternative 3: Outsourcing: Hiring CRM consulting company to do it.

Alternative 4: Outsourcing: Buying a currently existing CRM system from a vendor and modifying it if necessary

Alternative 5: Outsourcing: Buying a currently existing CRM system from a vendor and re-engineering the company's current process based on the processes in the CRM system purchased.

Process 5: Selecting the Optimum Alternative

Now, how do you create a list of criteria that will be used to measure the alternatives and make sure the alternatives will result in what you expected? Then, how you weigh them? Based on what? Look into the Hows in HoQ. In this case, *the computer system, customer-data processing, and production could be your criteria.*

The advantage of using the Hows in HoQ is that they are highly related to the predicted cash flow.

Process 6: Auditing / Controlling / Measurement System Building

For external measurements:

1. Customer-satisfaction rate: What is the current customer-satisfaction rate? What is the customer-satisfaction rate after the implementation of the CRM system?

For internal measurements:

1. Average response time: What is the average response time to customer requests? What is the average response time to customer requests after the implementation of the CRM system?
2. Average accuracy of the order status. What is the current average accuracy of the order status? What is the average accuracy of the order status after the implementation of the CRM system?

For the overall performance of the company

1. Customer-retention rate: What is the current customer-retention rate? What is the customer-retention rate after the implementation of the CRM system?
2. Newly generated revenue;
3. Revenue contribution per new customer;
4. Number of new customers; and
5. Average order-processing cost per customer.

Process 7: Approval and Execution

Appendix – Illustration of Activity Based Costing

We use the order-processing and customer-service department in this case as an example, and focus on the impact on the supporting costs on data processing. Some company put in an order of 1000 units, which is 5% of the total orders received that month. The following is the related cost and service information for the data-processing staff.

Assumptions made:

Only one data-processing staff member;

Labor rate: $7/hr;

Work hour: 160 hours / month;

Average time of service per request: a. manually: ½ hour

b. with the CRM system:0.001 hour

Average service-requests per order: 10

Using the traditional costing method, overhead cost allocation, the process cost for this order is:

$7 / hr * 160 hours * 0.05 = $56 (with or without the CRM system)

Using the ABC method, the process cost of this order is:

Without CRM:

$7 / hr * 0.5 hour * 10 requests = $35

With CRM

$7 / hr * 0.001 hour* 10 = $0.07

As you can see from this case, if the user adopts the traditional costing method, there is no way to see the service-cost difference between with and without CRM system.

Note: The above case is extremely simplified for demo purposes. Many factors have been ignored.

Appendix B

Survey Questionnaires

- English Version

(Note: Chinese version is available on request from the author)

Survey Questionnaire for Capital-Investment Decision-Making Models

This survey is to invite industry experts to validate models for capital-investment decision-making. The result of this survey will be used in Mr. Fang-Jen Chang's Ph.D. dissertation

Please fill out the survey at the end of each presentation accordingly.

Thanks for your valuable expertise and your participation in this research!

Best regards,

Fang-Jen Chang (a.k.a. Fred Chang)
Ph.D. Candidate
Wesley J. Howe School of Technology Management
Stevens Institute of Technology

Personal Information (Note: Personal information will be used only for reference credit in this dissertation. It will not be used for other purpose):

1. Current position in your company.

___ Chair of Board of Directors | ___ Chief Executive Officer

___ President | ___ Vice President

___ Chief Finance Officer | ___ Chief Operation Officer

___ Chief Information Officer | ___ Chief Engineer

___ Senior Manager | ___ Manager

___ Others(Specify):

2. How many years have you been in your current position?

3. How many years you have been in the PCB industry?

4. Please rate your general knowledge of the PCB industry on a scale of 1 –5.
Please circle one of following numbers.

Low Average High

1 2 3 4 5

5. Please rate your knowledge of the capital-investment decision-making process in the PCB industry on a scale of 1 –5.
Please circle one of following numbers:

Low Average High

1 2 3 4 5

6. Please rate your knowledge of Quality Function Deployment (QFD) on a scale of 1 –5.
Please circle one of following numbers.

Low — Average — High

1 2 3 4 5

7. Please rate your knowledge of Activity Based Costing (ABC) on a scale of 1 – 5.
Please circle one of following numbers.

Low — Average — High

1 2 3 4 5

Survey instructions

You will be asked few questions after each presentation section. In each section, you will be asked questions according to each Chang Model. For each question, please read the question description carefully and answer it by ***clearly circling a number*** based on your judgment. For example:

1 2 3 4 (5)

The meaning of the numbers is as following:

1 - Strongly Disagree

2 - Disagree

3 - Neutral

4 - Agree

5 - Strongly Agree

Part 1: The General Model

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. The General Model covers the major steps in capital-investment decision-making processes.	**1**	**2**	**3**	**4**	**5**
2. The General Model is applicable to PCB industry practice.	**1**	**2**	**3**	**4**	**5**

Part 2: The Model with QFD

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. The Model with QFD is applicable to the PCB industry.	**1**	**2**	**3**	**4**	**5**
2. The Model with QFD helps decision-makers focus on meeting customer requirements.	**1**	**2**	**3**	**4**	**5**
3. The Model with QFD helps identify the key processes required to meet customers' requirements.	**1**	**2**	**3**	**4**	**5**
4. The Model with QFD provides a good communication platform for decision-makers.	**1**	**2**	**3**	**4**	**5**
5. The Model with QFD provides decision-makers with good data quality for decision-making.	**1**	**2**	**3**	**4**	**5**
6. Model with QFD helps decision-makers to identify key decision-making criteria.	**1**	**2**	**3**	**4**	**5**
7. Overall, the Model with QFD is better than the General Model.	**1**	**2**	**3**	**4**	**5**

Part 3: The Model with ABC

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. The Model with ABC is applicable to the PCB industry.	**1**	**2**	**3**	**4**	**5**
2. The Model with ABC enhances decision-makers' understanding of the cost structure of a company's future services.	**1**	**2**	**3**	**4**	**5**
3. The Model with ABC enhances the quality of cost data used in decision-making processes	**1**	**2**	**3**	**4**	**5**
4. The Model with ABC provides good cost information about a company's future services.	**1**	**2**	**3**	**4**	**5**
5. The Model with ABC provides better data in decision-making processes than the General Model does.	**1**	**2**	**3**	**4**	**5**
6. Overall, the Model with ABC is better than the General Model	**1**	**2**	**3**	**4**	**5**

Part 4: The Model with QFD and ABC

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. The Model with QFD and ABC is applicable to the PCB industry.	**1**	**2**	**3**	**4**	**5**
2. Overall, the Model with QFD and ABC is better than the General Model.	**1**	**2**	**3**	**4**	**5**
3. The Model with QFD and ABC has the synergy effect of the Model with QFD and the Model with ABC.	**1**	**2**	**3**	**4**	**5**

Appendix C

Application Examples of Three Application Indices

Example 1 - Superior Index (SI) application:

Recently, there has been a demand for portable storage for computers. There are three companies propose to enter the market, and they have approached your company for funding. Based on the study by your evaluation team, all three companies could meet the physical product requirements. As a trend in the business, customers only buy "complete products". A complete product includes the physical product and its related services. As a result, the major benchmarking within these proposals should be on the market approaches and the operating processes. The key factors for these are identified as: A. Flexible delivery schedule and batch sizes; and B. Precise order control. The results of HoQ (see figure 1 on next page) and assessment of companies according to identified ECs are summarized in following table. The winner is company A.

	Allow user to select data item	On-line customer order handling & response	Inventory report on demand	Production planning on demand	Order status on demand	**Superiority Index Value**
Relative Importance in HoQ	**13**	**21**	**22**	**27**	**17**	
Utility assessment of Company A	5	8	4	6	7	**602**
Utility assessment of Company B	3	5	7	4	5	**491**
Utility assessment of Company C	7	6	6	5	3	**535**

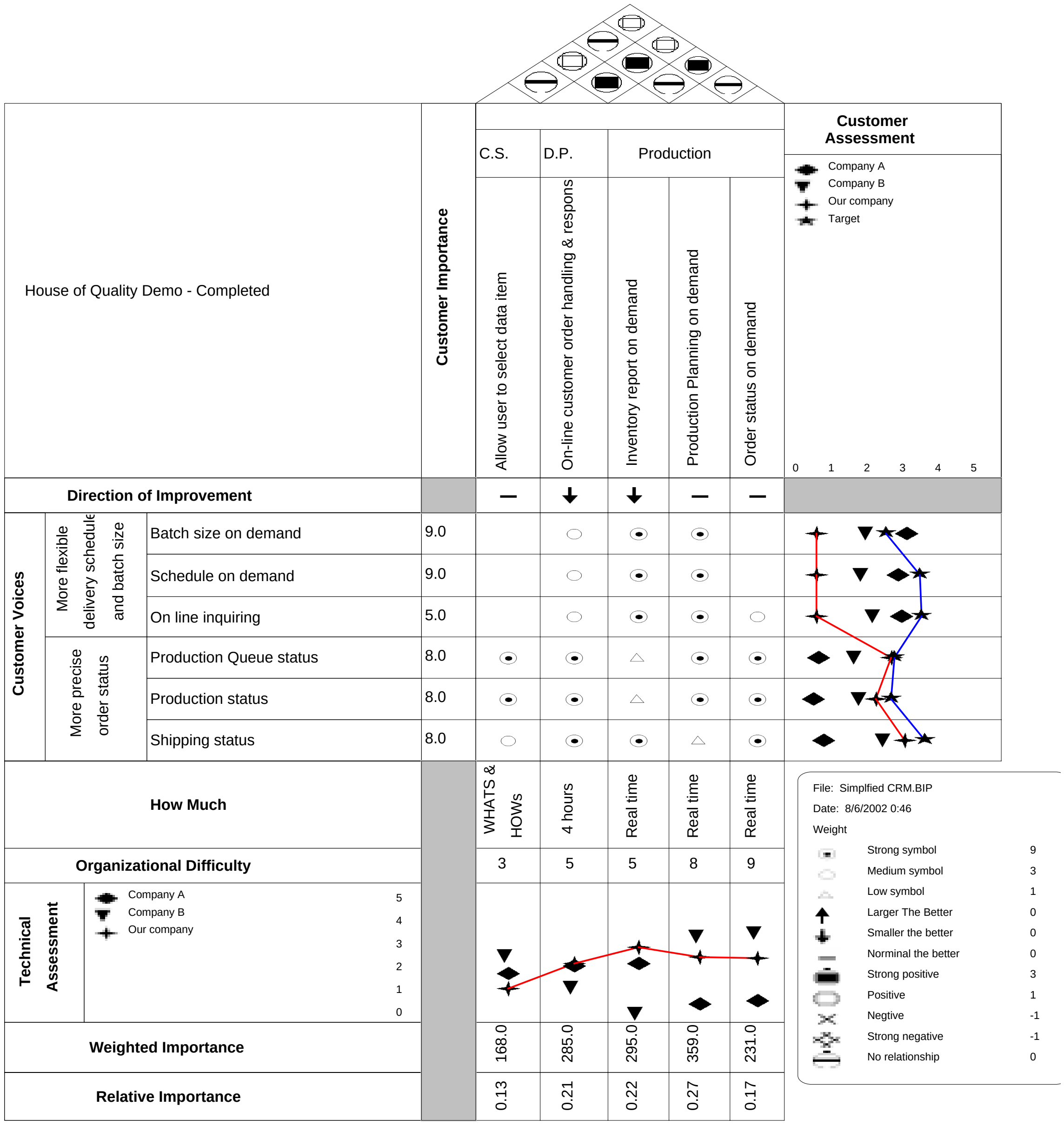


Fig. 1: House of Quality

Example 2 - Customer Satisfaction Index (CSI):

Your company is considering investing in a Customer Relationship Management system. Based on the customer surveys, the key customer requirements are identified as: A. Flexible delivery schedule and batch sizes; and B. Precise order control. The result of HoQ (see figure 2) and assessment of companies according to identified ECs are summarized in following table.

As a result, the confidence index of your target settings is 82.58, which is higher than that of the current best player. The proposal and target setting should be accepted.

	Allow user to select data item	On-line customer order handling & response	Inventory report on demand	Production planning on demand	Order status on demand	**Confidence Index**
Relative Importance in HoQ	**13**	**21**	**22**	**27**	**17**	
Competitor A	5	8	4	6	7	
Competitor B	3	5	7	4	5	
Competitor C	7	6	6	5	3	
Your company's target setting	7	7	8	5	6	
	CR_i: Confidence ratio of EC_i					
Competitor A	1/2	1	0	1	1	
Competitor B	0	0	1	0	1/2	
Competitor C	1	1/3	2/3	1/2	0	
Your company	1	2/3	4/3	0.5	3/4	
	(Relative importance of EC_i) * (CR_i)					
Competitor A	6.50	21.00	0.00	27.00	17.00	71.50
Competitor B	0.00	0.00	22.00	0.00	8.50	30.50
Competitor C	13.00	7.00	14.67	13.50	0.00	48.17
Your company	13.00	14.00	29.33	13.50	12.75	**82.58**

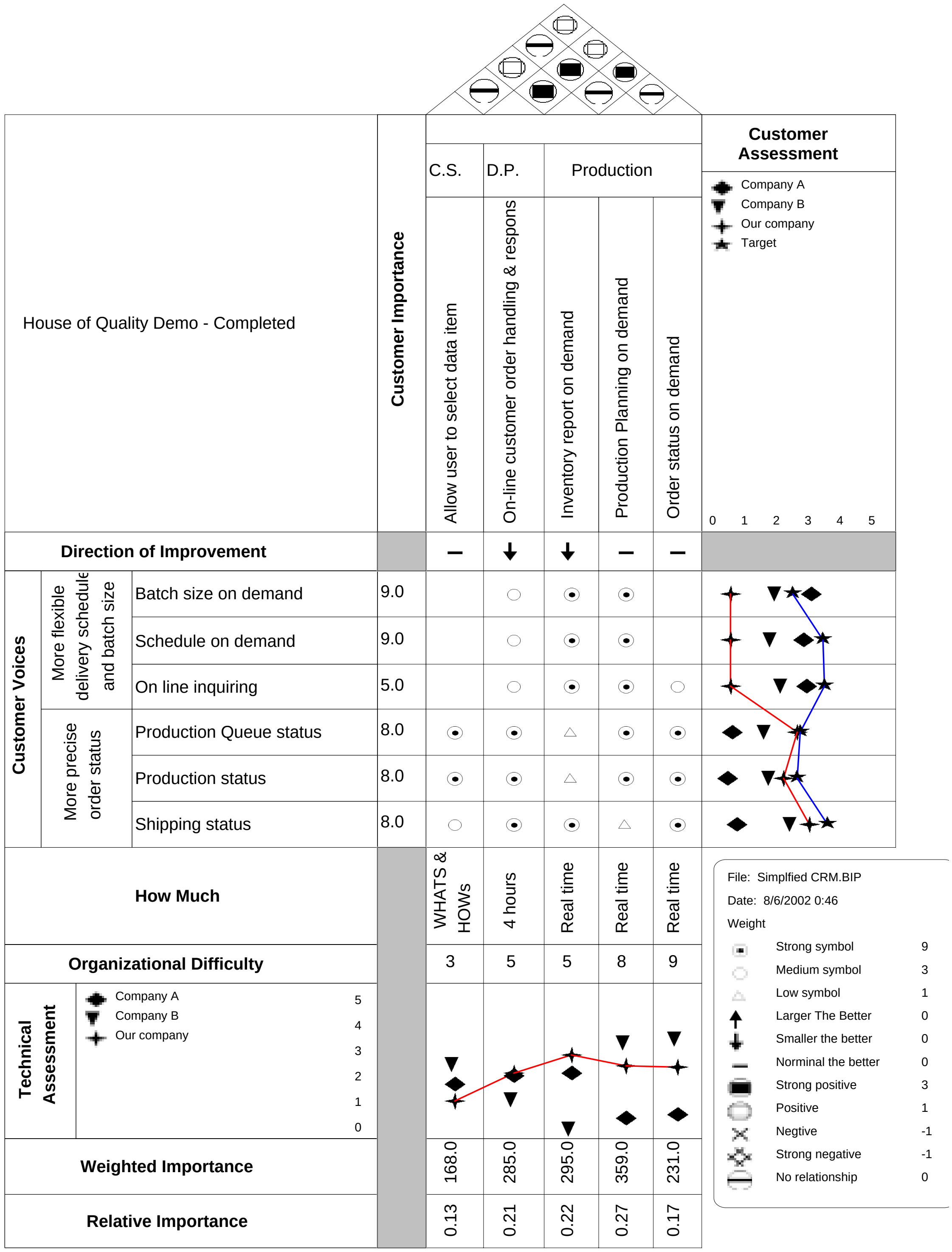
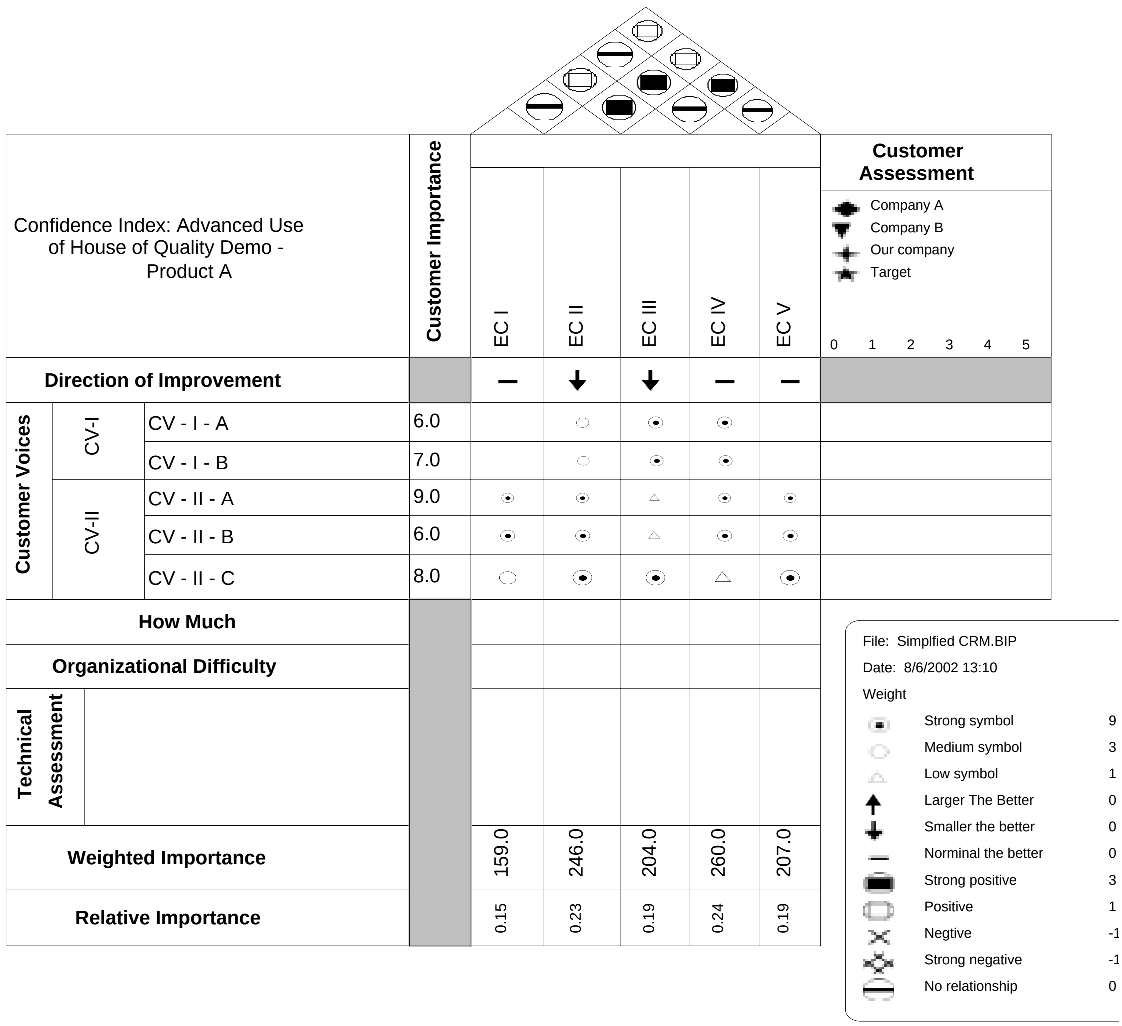


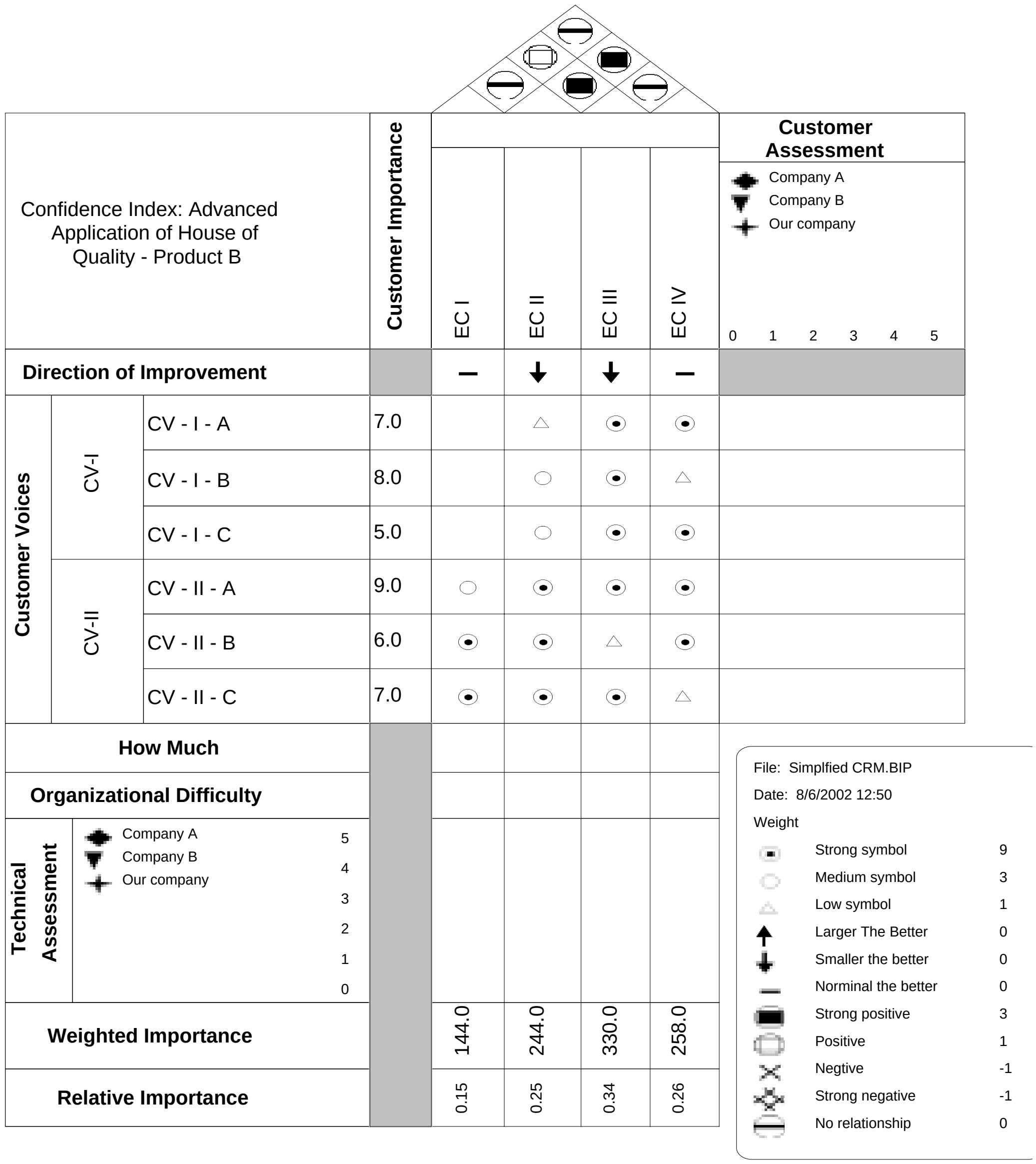
Fig. 2: House of Quality for example 2

Example 3 – Preferred Confidence Index (PCI):

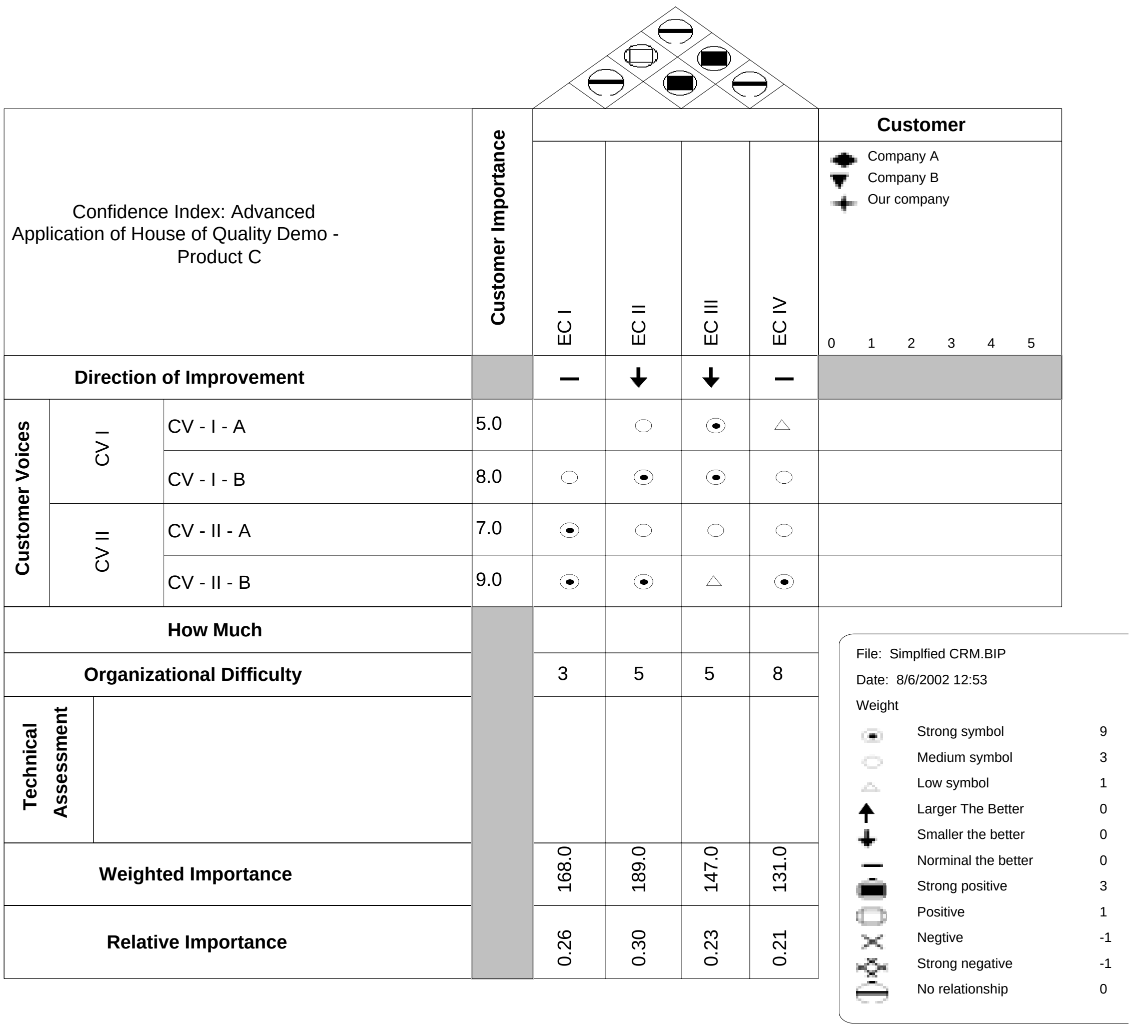
There are three proposals for three different new products to be evaluated. After the study, their economic and strategy evaluation results are roughly equal. You want to decide which one you should invest in. See following next pages for the HoQ for each product. The analysis work is shown in the tables followed. For product A, the PCI is 78.6. For product B, the PCI is 73.1. For product C, the PCI is 65.3. Product A is the winner.



	EC I	EC II	EC III	EC IV	EC V	**PCI**
Relative Importance in HoQ	**15**	**23**	**19**	**24**	**19**	
Confidence number	6	8	9	6	10	
(Relative importance of EC) * (CV) / 10	9	18.4	17.8	14.4	19	**78.6**



	EC I	EC II	EC III	EC IV	PCI
Relative Importance in HoQ	**15**	**25**	**34**	**26**	
Confidence number	5	8	9	6	
(Relative importance of EC) * (CV) / 10	7.5	20	30.6	15.6	**73.1**



	EC I	EC II	EC III	EC IV	**PCI**
Relative Importance in HoQ	**26**	**30**	**23**	**21**	
Confidence number	4	6	8	9	
(Relative importance of EC) * (CV) / 10	10.4	18	18.4	18.9	**65.7**

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